A SURVEY OF IRISH ELECTRONIC INDUSTRIES TOWARDS DEVELOPMENT OF A LOW COST MRP SYSTEM TO ENHANCE THE EFFECTIVENESS OF THEIR INVENTORY CONTROL

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M.Eng. 1991

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BY

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This thesis is submitted as the fulfilment of requirement for the award of Master of Engineering (M.Eng) by research to:

DUBLIN CITY UNIVERSITY

Sponsoring Establishment: EOLAS

September 1991

DECLARATION

I hereby declare that all the work prepared in this thesis was carried out by me at Dublin City University during the period September 1989 to September 1991.

To the best of my knowledge, the results presented in this thesis originated from the present study except where references have been made. No part of this thesis has been submitted for a degree at any other institution.

SIGNATURE OF CANDIDATE: ______________________

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ABSTRACT

This thesis is predominantly concerned with the study of inventory control practices within the electronics industry in Ireland.

The study of the inventory control system has been carried out under three main interrelated sections:

Industrial Survey

Development of an MRP Model

Development of a Material Flow Simulation Model

First, an industrial survey carried out to identify the common problems and challanges related to the electronics industry sector with respect to their inventory control systems.

The results of the industrial survey representing 44 companies are presented. The survey classifies the Irish Electronics industry sector in terms of company size, product structure and MRP levels.

Second, based on the industrial survey results a low cost MRP model has been developed to enhance the effectiveness of their inventory control system. The model has been solved for a variety of product structures using standard mathematical programming packages. The results obtained are compared to those of standard MRP hot sizing techniques.

The third section involves the development of a material flow simulation model using the SIMAN simulation package. The model is tested under a variety of operating conditions and performance statistics collected and analysed.

ACKNOWLEDGEMENT

I would like to express my appreciation to **Dr. M. A. El Baradie** for his guidance and supervision during the course of this project.

I would also like to thank **Mr. James O'Kane** of Staffordshire Polytechnic and **Dr. Michael O'Heigeartaigh** of Dublin City University who introduced me to **SIMAN** and **SCICONIC** respectively.

Table (1.1): List of Mnemonics.

LDC	Less Developed Country.
NIC	Newly Industrializing Country.
MNC	Multi-National Company.
IDA	Industrial DevelopmenT Authority.
CTT	Irish Export Board
SFADCO	Shannon Free Airport Development Company.
APICS	American Production and Inventory Control Society.
R&D	Research and Development.
MRP	Material Requirement Planning.
MRP II	Manufacturing Resource Planning.
WIP	Work in Progress.
BOM	Bill of Material.
MPS	Master production Schedule.
IRF	Inventory Record File.
JIT	Just in Time.
PTR	Process Time Ratio.

CHAPTER 1
INTRODUCTION

In recent years western manufacturing circles have begun to place a great deal of emphasis on the reduction of inventory at all stages within the manufacturing process. Raw Material stocks, Work-in-Progress, and the stocks of Finished Goods have all been earmarked for indepth analysis and reduction. The reason for this new departure was primarily, the realization that a significant percentage of working capital was being needlessly tied up in these stocks. Capital investment costs were also been 'sunk' into the building of large storage facilities to house these stocks. This emphasis on inventory reduction sowed the seeds for the development of two manufacturing philosophies, which ideally offer two quite different solutions to the same problem. - These two philosophies are termed Manufacturing Resource Planning (MRP II), and Just-In-Time (JIT).

The main theme of this thesis is inventory control, and with this in mind, an integral aspect of each philosophy is examined in detail. The first section of this thesis is however, mainly concerned with establishing the importance attributed to inventory control techniques within Ireland today. A survey questionnaire was designed to evaluate the extent to which MRP II and JIT have permeated the ranks of the various sections of the electronics industry. Chapter 4 presents a brief review of the effects of industrial policy on the internal make-up of the industry, and with this in mind presents a discussion of survey results. Background information to this chapter may be found in chapters 3, 5 and 6.

Within MRP II, a major area of contention has been the ability of MRP systems to generate optimum requirements. Chapter 6 develops an alternate MRP model and demonstrates it's ability to solve the requirements problem for a variety of product structures. The models are solved using two standard mathematical programming packages, and the limitations placed on the product structures by the capacity of each package, are investigated. Finally the developed models' generated requirements are compared against that generated by some of the more widely used Lot Sizing procedures. Background to this chapter may be found in chapter 2, 3 and 5.

The Just-In-Time philosophy controls and monitors material flow on the factory floor, through the use of a Kanban system. Chapter 7, describes the Kanban system and Chapter 8 develops a Kanban simulation model. The Kanban model is run under a variety of operating conditions and the model's performance is evaluated, based not only on inventory levels, but also on a number of other performance characteristics. Chapter 2 reviews some of the background papers for this section.

CHAPTER 2
LITERATURE SURVEY

2.1 INTRODUCTION

The mathematical modelling of material requirement planning systems falls into two distinct sections - namely scheduling and requirements generation. In this instance however our interest lies only in requirements, and the generation of optimum time phased order requirements, through the use of lot sizing techniques.

Typical systems in use today employ single-stage uncapacitated algorithms, which are applied sequentially to different levels, ignoring the concept of inter-level dependency. It is ironic to think that the backbone of requirement planning systems, - the ability to deal with inter-level dependency - is ultimately ignored in the preparation of the final results and hence serves only to produce sub-optimal results.

Over the past two decades research into lot-sizing procedures has seen growth in two directions. The first approach encompasses the work of Zangwill [1], Love [2], and others. It concentrates on the development of algorithms which yield optimal solutions to the lot-sizing problem. The second, is based upon the application of single level heuristics, but attempts are made to account for costs at each stage, and in so doing, account for interdependencies between items. New [3], Afentakis et al. [4] have both worked in this area. Optimization is the common factor in both approaches and it is this which distinguishes present research from practise. The former method however seeks to produce optimal requirements, the latter to optimize requirements produced.

The solution to producing optimal requirements lies in the use of mathematical programming techniques. As objective funtions and constraint equations become more complex, and the problem size increases, processing time, and its reduction, becomes increasingly important. With this in mind, new solution methods, exploiting certain characteristics of the constraint matrix are constantly being sought.

The question confronting many manufacturers today, especially those thinking of installing or upgrading an MRP system, is whether or not they are in fact being cheated by being offered systems which do not produce optimum results.

The following review is not by any means an exhaustive account of the development of lot sizing techniques and procedures, but a brief chronological review of work carried out on the topic, in order that:

a) The disparity between theoretical approaches to the lot sizing problem, and the actual heuristics employed may be highlighted.

b) The potential that a good optimal approach to the lot sizing procedure would offer a manufacturer, in terms of saved investment might be brought to the fore.

2.2 MRP LOTSIZING MODELS

2.2.1 The first lot sizing model was introduced by Wilson (see Browne et al. [5]) in 1915. It was called the Economic Order Quantity (EOQ). This model, and others, such as the Period Order Quantity (POQ), and Part Period Balancing (PPB), which were later developed from the Economic Order Quantity are still much in evidence today. These methods seek a trade-off between set-up (or order) costs and carrying costs, but all, are based upon three assumptions, namely

1. Cost structure is concave.
2. Demand for the item is assumed uniform and to occur continuously over time.
3. All models are derived using differential calculus. (Browne et al. [5])

The 1950's however brought about a change in the fundamental approach to lot sizing with the postulation that time could be divided into discrete time intervals, and that demand for these periods could be forecast, or else was known. In order to determine optimal requirement schedules, mathematical programming techniques were called upon. One of the first mathematical programming models was introduced by Wagner

Table (2.1):Zangwill Model 1

Model Summary	Objective Function	Constraint Equation
Zangwill (1969) (instantaneous production).	min: $\sum_{i=1}^{N}\sum_{t=1}^{T}(C_{it}\,P_{it}+H^{+}_{it}\,I^{+}_{it}+H^{-}_{it}\,I^{-}_{it})$ **(2.1)**	$\sum_{i=1}^{N}\sum_{t=1}^{T}P_{it} = \sum_{i=1}^{N}\sum_{t=1}^{T}D_{it}$ **(2.2)**
Single facility,multi-period,backlogging. Production,holding shortage costs.		$P_{it}+I^{+}_{it-1}-I^{-}_{it-1}-I^{+}_{it}+I^{-}_{it} = D_{it};$ $t=1..T,i=1$ **(2.3)**
Concave costs. Dynamic Algorithm.		$I^{+}_{i0}=I^{-}_{i0}=I^{+}_{iT}=I^{-}_{iT}=0;i=1$ **(2.4)** $P_{it},I^{+}_{it},I^{-}_{it}\geq 0;$ $t=1..T$ **(2.5)**

and Whitin in 1958, (see Zangwill [1]). It was based around the dynamic programming approach, and assumed identical costs in each period. The model referred only to a single product, produced on one facility but in multiple periods. Demand was not allowed to accumulate.

2.2.2 Zangwill [1], refers to the Wagner-Whitin model [Table (2.1)] and demonstrates how it can be represented in terms of a network (the transhipment variety). A concave cost structure is assumed, which is shown to result in an optimal flow which possesses certain peculiar properties. These properties are termed extreme flows, (arborescences), and arise because, in single source networks with optimal concave costs optimal flows will be extreme, and as such, nodes can have at most one positive input. It is not feasible therefore to both place an order and receive goods into stock within the same period. This relationship between concave costs and extreme flows is very important, It the marginal costs of holding an item from one period to the next is greater than increasing the order size to be placed then the latter is more feasible, - due to non-increasing marginal costs.

Zangwill [1] extends the Wagner-Whitin model with a single facility and multi periods to allow backlogging, (cumulating demands). [Table (2.2)]. This is done by dividing up the inventory variable to represent both shortage and surplus amounts. Instantaneous production is assumed, although Zangwill [1] says that all that is required if lead times are to be accounted for is a simple redefinition of the time scale. The model is explained using network techniques and some important properties of the optimal flow are developed. A dynamic algorithm based on the model is presented.

The second part of Zangwill's paper again deals with the single product multi-period model but this time multi-facilities in series are assumed. This model is also described in terms of network theory, and the properties of the resultant extreme flows are examined. A short three facility, three period example is included to help explain the algorithm.

Table (2.2): Zangwill Model 2

Model Summary	Objective Function	Constraint Equation
Zangwill(1969). (Instantaneous Production).	*Min*: $\sum_{i=1}^{N} \sum_{t=1}^{T} (C_{it} P_{it}+H_{it} I_{it})$	$P_{it}+I_{it-1}-I_{it}=D_{it}$; $t=1..T,\ i=1.$ (2.7)
Single facility Multi-period. Production and Holding costs.		$I_{i0}=I_{iT}=0; i=1$ $P_{it}, I_{it}=0; i=1$ (2.8)
Concave costs. Dynamic Algorithm.		$\sum_{i=1}^{N}\sum_{t=1}^{T} P_{it} = \sum_{i=1}^{N}\sum_{t=1}^{T} D_{it}$ (2.9)

2.2.3 Love [2], capitalizes on some of Zangwills' observations to develop a somewhat less generalized verson of Zangwill's multi-facility series model, namely,

1. Optimal flow allows only one positive input per node. [Table (2.3)]
2. Extreme flow, and hence optimal flow requires that the flow of material entering a node must be equivalent to the total demand placed upon destination nodes serviced by that node.

The developed model is based upon the idea of instantaneous production, and a concave cost structure made up of both production and holding costs. The first algorithm presented refers to a finite planning horizon of T periods, and introduces the idea of nested schedules. This requires that if production does not take place at facility $i+1$, within a specified time period, then facility's i production is also zero within that period.

The network diagrams developed in accordance with nested schedules are characterized by a much greater degree of organisation than in previous models. The dynamic algorithm accompanying the model is also much simpler, requiring less iterations to achieve results. The algorithm is clarified by example. Nested schedules however, like backlogging have no real place within the realms of requirements planning, for the following reasons:

1. Production must be completed within the time period it is initiated, thus limiting the state in which inventory is held to that of end products and raw material.
2. By virtue of the above, lead times can not be included by simply redefining the time scale.

2.2.4 Crowsten et al. [6] present yet another dynamic algorithm, this time based upon the nested schedules of Love. The model described [Table (2.4)] is for multi-facility, assembly product structure over a finite planning horizon. Production is again to occur instantaneously, with a concave cost structure. Inventory holding costs however, making use of the concept of echelon costs - first introduced by Clark et al. [7] - have a linear structure. The main thought behind the echelon costs is that

Table (2.3): Love Model

Model Summary	Objective Function	Constraint Equation
Love (1972) (Instantaneous Production).	*Min:* $\sum_{i=1, t=1}^{N\ T}(C_{it}\ P_{it}+H_{it}\ I_{it})$ (2.10)	$P_{it}-P_{i+1t}+I_{it-1}-I_{it}=0;$ $i=1..N,t=1..T.$ (2.11)
Multi facility(series), Multi period. Production,Holding costs.		$I_{it}=0,P_{it}I_{it}\geq 0;$ $i=1..N,t=1..T$ (2.12)
Concave costs. Dynamic Algorithm.		*Optimal flow:* (*i*) $I_{it-1}-P_{it}=0;$ $i=1..N,t=1..T.$ (*ii*) $I_{it-1}+P_{it}=\sum_{k=a}^{b}X_{kN+1};$ $t\leq a\leq b\leq T$ (2.13)

holding costs should be dependant upon the value added at each stage within the process. Unlike the preceding papers, the algorithm presented, attempts to account for the assembly product structure - whereby a facility can have a finite number of predecessors, but only one successor. Crowsten et al. [6], rejects the network interpretation of the model, and used production profile vectors to explain the workings of the model. Also presented in the paper is a branch and bound version of the algorithm, using a version of the Wagner-Whitin algorithm to determine the bounds required to exclude non-optimal solutions. The number of operations required to determine the optimal solution is greatly increased.

The dynamic programming models discussed have three common and very important failures, in terms of todays manufacturing needs.

1. In order to produce optimal output efficiently, a number of unrealistic constraints, such as operating with nested schedules must be placed on the model.
2. General assembly structures, whereby an item may have a number of parent items, and a number of successors greatly complicate dynamic algorithms performance.
3. No attempt to take account of lead times has been made other than a redefinition of the time scale.

This paper would seem to herald the end of the dynamic approach to lot-sizing in literature.

2.2.5 Although Schwarz and Schrage [8], take no account of discrete time intervals, and therefore their inventory model has no real application in M.R.P systems, the paper does present interesting arguments in favour of

1. Branch and bound procedures
2. System myopic policies

The branch and bound model developed is for the one parent assembly model.

Table (2.4): Crowsten et al. Model

Model summary	Objective Function	Constraint Equation
Crowsten, Wagner (1975) (Instantaneous production)	min: $\sum_{i=1, t=1}^{T\ N} (C_{it}\ P_{it}+H_{it}\ I_{it})$ (2.14)	$I_{it}=I_{it-1}+P_{it}-P_{j(i)t}$; $i=1..N, t=1..T$ (2.15)
Multi facility (assembly), Multi Period. Production, Inventory costs		$P_{it}, I_{it} \geq 0$; $i=1..N, t=1..T$ (2.16)
Concave Production costs, Linear Holding Costs.		*Optimal flow: as before* (2.17)

The model developed [Table (2.5)] is based on the assumption that an optimal order policy exists, whereby the ratio of time lot size at stage i, to a successor stage is integer. The inclusion of set-up costs and echelon holding costs results in a convex objective function and lower bounds to the problem may be generated using the economic order quantity. A better bound may be found however by minimizing the cost at each stage separately, and checking results to ensure that the lot size generated at each stage i is less than that generated at an immediate predecessor stage. If this is not the case then the costs at stage i must be modified, based upon the costs at an immediate predessor stage, and the lot size regenerated.

If the lot size ratios at stage i and its immediate successor stages are integer, than no branching takes place, otherwise the ratio is assigned an integer value and the relevant costs are again modified, until all constraints satisfied.
The paper finally presents a discussion on system myopic policies, which are designed to optimize a given objective function with respect to any two stages, ignoring multistage interaction effects. The advantages of myopic policies are listed as:

1. Easy to apply compared to branch and bound techniques.
2. Easy to understand.
3. Require less information than branch and bound.
4. Fast and very easy to compute.
5. Costs generated are very close to that of branch and bound.

2.2.6 Dorsey, Ratcliffe and Hodgson [9], present an efficient one pass algorithm for the facilities in parallel problem - M facilities, any of which can fully process a product-. The model formulation [Table (2.6)] differs from any previously encountered. For each item, in each period a constant W_{kt} is defined. This represents the number of times product k must be scheduled in order to meet demand. Its calculation is based on constant production rates, existing inventory, and demand. Each individual item's cost structure is used to develop an internal indexing term, upon which the item's scheduling priority per period is based. Therefore items which incur the lowest holding cost would be scheduled first, thereby producing lowest overall costs.

Table (2.5): Schwarz et al. Model

Model Summary	Objective Function	Constraint Equation
Schwarz ,Schrage (1972) (Instantaneous)	$$Min: \sum_{i=1}^{N}\left(\frac{K_i D}{Q_i}+\frac{H_i Q_i}{2}\right)$$ (2.46)	$$Q_i=n_i Q_{s(i)};\ i=1..N;\ n_i \geq 1, integer$$ (2.47)
Multi facility (assembly) Single product. Set-up,echelon holding costs.		$$h_i=(1+\rho_i)h_i^1+2\rho_i\sum_{k\in A(i)} h_k^i$$ (2.48)
Convex cost. Branch and bound.		

The approach adopted in this paper is of interest, both because of the model formulation and also because it provides insight into hierarchial requirements planning. The approach adopted however cannot be expanded to develop efficient algorithms for the solution of general assembly product structure.

2.2.7 The paper of Glover et al. [10], marks the emergence of generalised networks onto the computer based production planning stage. The paper gives an informative account of what a generalized network is, and its relationship to a linear program, - similar to an L-P but having certain features which can be exploited in finding a more efficient solution procedure -. The advantages of generalised networks over the more general class of linear programs fall into two distinct areas.

1. Degree of solution efficiency.
2. Graphical interpretation.

The paper discusses how a coefficient matrix of certain linear programs can be transformed via a set of linear transformations to a "node incident" matrix, with no more than two elements per column.

A distinction is made between generalized networks and pure processing networks. Shortest path, maximum flow, assignment, transportation, transhipment, all fall under the pure processing class initially or by linear transformation, by virture of matrices which consist of ones (not more than two per column) and zeros. The generalized networks however allow integer constants other than one into the matrix.

The latter stage of the paper examines the efficiency of a computer code NETG, used to solve generalized networks and identifies the following as being the critical factors in determining solution speed.

1. Start up procedures
2. Pivot selection techniques
3. Degeneracy
4. Pivot tie breaking rules
5. Big M. valves

Table (2.6): Dorsey et al. Model

Model Summary	Objective Function	Constraint Equation
Dorsey et al. (1975) (Instantaneous production)	min: $\sum_{\substack{t=1 \\ k=1}}^{t\ N} (2T-2t+1)\Psi_k X_{kt}$ (2.49)	$\sum_{k=1}^{T} X_{kt} \leq M;$ $t=1..T, k=1..M$ (2.50)
Single Component, multi product, multi facilities (parallel). Fixed Production and Hollding costs.		$\sum_{j=1}^{T} X_{ij} \geq \omega_{kt}$ $X_{kt} \geq 0, integer$ $k=1..M, t=1..T.$ (2.51)
Convex Costs. One pass Algorithm.		

2.2.8 The algorithm presented by Dorsey et al. [9] becomes the basis of a multi-item, series, multi-stage algorithm developed by Gabbay [11] [Table (2.14)]. The underlying principle is that certain multi-stage systems can be treated as a sequence of single stage problems. Restrictive assumptions regarding costs however must be made. Production costs must decrease linearly with time, at each facility and for each item, - ensuring production as late as possible -. Holding costs must increase with each stage -ensuring that the item is kept in its cheapest form as long as possible.

The initial form of the model is similar to that of Zangwill [1], with the noticeable exceptions that:

1. The objective function takes on a linear form.
2. A production constraint is included at each facility and in each period. But for only one resource.

Before attempting to solve the model, Gabbay [11] eliminates the inventory variable from the model and so reduces all equations to being expressed in production terms. An aggregate production vector is introduced and defined recursively from stage i to stage 1, (at each stage and in each period). Treating each stage as being independent, the aggregate production at stage $i+1$ in period t becomes the demand in stage i, period t. Feasibility conditions are reduced to that of a single stage system, namely that aggregate cumulative capacity for each item, and stage over the planning horizon must exceed or equal aggregate demand.

The paper also derives on interesting relationship between aggregate production and capacity. Because cumulative production is being minimized, no inventory will enter or leave a stage where total capacity is sufficient to satisfy demand.

The algorthim presented aggregates production and then disaggregates, item by item, period by period. It is then used as a basis for the multistage case where instead of disaggregating, modified planning horizons are introduced and the single stage algorithm used to solve the problem over each period. Hierarchial or aggregate planning has two main advantages:

Table (2.7): Gabbay Model.

Model Summary	Objective Function	Constraint Function
Gabbay (1979) (Instantaneous Production)	min: $\sum_{\substack{k=1\\i=1\\t=1}}^{M\ N\ T} (C_{kit}P_{kit}+H_{kit}I_{kit})$ (2.52)	$I_{kit-1}-I_{kit}+P_{kit}=P_{ki+1t};$ $k=1..m, i=1..N-1,$ $t=1..T.$ (2.53)
Multi product,multi facility(series). Production,Holding costs		$I_{kit-1}-I_{kit}+P_{kit}=D_{kt};$ $k=1..m, t=1..T.$ (2.54)
Linear costs Multi-pass Algorithm.		$\sum_{k=1}^{M} m_{ki}P_{kit}\leq\overline{P_{it}}$ $i=1..M, t=1..T.$ $I_{ki0}, I_{kiT}=0$ $Pkit, I_{kit}\geq 0;$ $i=1..N, t=1..T, k=1..M.$ (2.55)

1. It reduces complexity of problem.
2. Postpones any decision-making until more accurate data is available.

The assumptions made early in the model's development in relation to costs together with the assumption that production is proportional to item cost are however very restrictive.

Aggregate planning techniques will probably have greater and more successful applications at higher levels within the manufacturing control structure rather than within the confines of material requirements generation.

2.2.9 Steinberg and Napier [12], monopolised on the work of Glover [11] and others to present an inventory model which could be formulated as a generalised network. The model is of the assembly variety, but can only accommodate single parents. The objective function is obviously linear, incorporating production costs alone.
[Table (2.8)].

The model is comprehensibly formulated using a multi-source network interpretation. both inventory and production variables are identically represented as charges (or flows) incurred between component and manufacturing nodes respectively. Costs are similarly represented as fixed charges between nodes. The indexing method used to both construct and differentiate between terms within the model is complex and confusing. Once formulated, Steinberg et al. [12] uses a mixed integer programming package to obtain results for problems of up to four levels, three products and six time periods. Processing time was found to be over seven minutes, for even small problems.

Three important points in relation to solution times were made.

1. Very large problems can be decomposed into smaller product families, where commonality exists within the family, but not without. Each problem can then be solved independently.

Table (2.8): Steinberg et al. Model

Model Summary	Objective Function	Constraint Equation
Steinberg,Napier (1980) (Instantaneous Production)	min: $\sum_{(i,j)\in N} C_{ij}X_{ij}$ (2.18)	*Network form*: $-\sum_{(i,j)\in N} f_{ij}X_{ij} + \sum_{(i,j)\in N} h_{ji}X_{ji}=b_i$ (2.19)
Multi facility,(assembly) Multi period. Holding,production, purchasing costs. Linear Costs. Linear programming.		$L_{ij}\le X_{ij}\le U_{ij}$; $\forall_{ij}\in N$ (2.20)

2. Computational effort might further be reduced by finding a more efficient method of determining upper and lower bounds on the various arcs.
3. A solution method which exploits the topological structure of the model may prove very efficient.

2.2.10 The Steinberg and Napier [12] model, generated some controversy in lot-sizing circles.The reasons for this were presented in a paper published by Thomas et al. [13].

Firstly the S-N formulation (Steinberg and Napier), present results of small assembly product structures, where quantities per parent items are represented as side constraints. Thomas et al. [13] say that the presence of these side constraints make it impossible to solve the model using existing network codes.

Secondly, as seen in the S-N formulation, the network consists of

1. Purchase, component, assembly nodes.
2. Purchase, inventory, manufacturing, fixed charge arcs.
3. Side constraints to maintain proportionality of requirements.

Each node is labelled according to product level and period, and therefore requires six subscripts to identify each node. Thomas [13] points out that this is too cumbersome and confusing.

Thomas [13] presents a final point relating to the formulation of side constraints within the S-N model, and presents a more efficient method which reduces the number of constraints.

An alternate model formulation is presented [Table (2.9)] in which holding costs and set-up costs are included in the objective function and the major constraint is the standard form of the material flow equation.

Table (2.9): Thomas et al. Model

Model Summary	Objective Function	Constraint equation
Thomas et al. (1981) (Lead time inclusion)	*Min*: $\sum_{i=1}^{N}\sum_{t=1}^{T}(C_{it}\ P_{it}+H_{it}\ I_{it}+S_{it}\ Y_{it})$ (2.21)	$I_{it}+P_{it-L_i}-\sum_{j\in S_i}A_{ij}\ P_{j(i)t}-I_{it}=D_{it};$ $i=1..N, t=1..T$ (2.22)
Multi facility,multi period(assembly). Holding ,Set-up and Production Costs.		$P_{it}-MY_{it}\leq 0;$ $Y_{it}\in(0,1)$ (2.23)
Linear costs. Linear Programming.		$P_{it}, I_{it}\geq 0$ (2.24)

2.2.11 Blackburn and Millen [14] present results from the pursuit of research along an alternate path to the optimum solution, - the sequential application of a single stage algorithm with a set of modified costs in an attempt to account for interdependencies between items. For explanations of the various single stage algorithms see Chap.6. The work of Blackburn and Millen owes much to that of Schwarz and Schrage [8], and their continuous time model.

The model seeks to minimize holding costs and set-up costs. Production costs are assumed zero. The concept of echelon stock at stage is incorporated into the model. The objective function is described in terms of set-up and echelon costs, together with an order interval variable r_i (specified in time periods) which established the rate of placement of orders. The lot-sizing problem therefore reduces to finding a set of n_i values which minimises the average cost period. These values are determined iteratively down through the product structure by evaluating k_i, (ratio of n_i stage i to n_i at parent stage. The k_i values represent the number of orders from parent stages which are combined into a single order at stage i. These values once determined can then be used to minimize costs. The paper presents five methods of determining these k_i values.
The empirical work described in the paper centres around serial (two and three stage) and assembly (five stage) systems. In both cases varying combinations of single level heuristics, with and without modified costs were used in order that the performance of the adjusted cost methods could be ascertained. In each case, the adjusted cost methods retained a computational efficiency comparable to single stage lot-sizing algorithms.

2.2.12 The previous model formulation, Blackburn and Millen [14], is similar to that of Akentakis et al. [Table (2.10)]. Not only does the model seek to minimise set-up and holding costs but also included is the concept of echelon holding stock. The material flow constraint equations are rearranged in terms of echelon stock. Because of this demand terms generated internally (at intermediate levels), must be expressed in terms of echelon stock also.

Table (2.10): Akentakis et al. Model

Model Summary	Objective Function	Constraint Equation
Akentakis et al. (1985) **(variable lead time)**	min: $\sum_{i=1,t=1}^{N\ T} (S_{it}\ Y_{it} + H^1_{it}\ E^1_{it})$ **(2.37)**	$E^1_{it-1} + P_{it} - E^1_{it} = A_{ij} D_{j(i)t};$ $i=1..N, t=1..T$ **(2.38)**
Single Product, **multi period,multi facility(assembly).** **Set-up,Echelon Holding costs.**		$-E^1_{it-1} + A_{ij} E^1_{j(i)t} \leq 0;$ $i=1..n, t=1..T.$ **(2.39)**
Linear costs. **Branch and Bound.**		$-E^1_{it} \leq 0; t=1..T$ $P_{it} \leq Y_{it}; 1=1..N, t=1..T$ $Y_{it} e (0,1); P_{it}, I_{it} \geq 0$ **(2.40)**

Akentakis et al. [4] have not presented an optimal solution to the problem, and because of this a comparison can not be made between this model's performance and that of Blackburn and Millen [14]. Some properties of the optimal solution are presented. The first of these is similar to the nested schedules idea of Love [2] and Crowsten et al. [6] in that if, facility $i+1$ produces in period t, then the facility i must also have produced. The second property, follows from the first, and states that if production at any facility i, period t is optimal, then an optimal production schedule exists at facilities $i+1$ to final assembly (straight path). The third property also makes use of Love's [2] result for an optimal solution which says that there exists an optimal solution in which each node can have only one positive input. This implies that the search for optimality is limited to the subset of all feasible solutions. This subset consists of the set of all plans in which item i appears in period t, only when the echelon stock of i, at the end of the previous period is zero. The final property relates to branch and bound solutions and the use of Lagrangian relaxation to tighten the bounds. It states that shortest route algorithms can be used to solve the problem following treatment using Lagrangian relaxation.

Akentakis [4], shows how this new treated function may become the bound (lower) for the problem, and shows how the bounds themselves can be optimized. The upper bounds are generated using a single level heuristic. The mathematics of obtaining bounds are fairly complex and a background in Lagrangian would be advantageous.

The final section of the paper deals with the performance of the branch and bound algorithm itself, and the testing of four different assembly systems each with a varying number of nodes and levels. The algorithm performed well in all cases and computing time deemed reasonable. Large scale problems however were stated to be beyond the scope of the algorithm and the usual constraint of only one parent per item applied.

Table (2.11): Prentis et al.model

Model Summary	Objective Function	Constraint Equation
Prentis et al. (1985) (Constant lead time)	*Min*: $\sum_{i=1}^{N}\sum_{t=1}^{T} (H_i I_{it} + C_{it}^{(B_i)} P_{it} + S_i Y_{it})$ (2.41)	$W_{it} = -I_{i0}^{1} + \sum_{r=1}^{T} (D_{ir} + \sum_{j\in S(i)} A_{ij} P_{jr})$ (2.42)
Multi facility, multi period (assembly). Holding, Production set-up costs, price breaks.		$U_{it} = Max[0; W_{it} - \max (W_{i0} - W_{it-1})], \forall_{it}$ (2.43)
		$P_{it-L_i} = 0$ *if*: $\sum_{r=1}^{t-1} X_{it-L_i}$ *else*: $\sum_{a=t}^{k\le T} U_{ia} \forall\ t$ (2.44)
		$I_{it} = I_{it-1} + P_{it-L_i} - U_{it};\ \forall t$ (2.45)

2.3 MRP II LOT SIZE MODELS

2.3.1 Zahorik et al. [15], formulates a multi-facility, multi-period, multi-product model for the parallel series product structure. Each product however must go though a similar sequence of production steps. [Table (2.11)].

The model is formulated very comprehensibly with the objective function consisting of both production and holding costs. The constraint equations include the usual material balance constraints but added to these are a number of capacity constraints. The first of these limits the total amount of production at any stage. A similar restriction is also placed on inventory at any stage. These two constraints are termed bundle constraints. (Constraints on total thruput at any stage). Upper bounds are also placed on individual production and inventory variables at each level.

In order to solve the presented model, the bundle constraints must be limited to occur in the following three forms:

1. On inventory at any stage.
2. Total production at the final stage.
3. Total production and inventory at any stage.

Generally speaking, bundle constraints cannot be modelled as networks however the paper reveals network properties of bundle constraints as long as the planning horizon is less than or equal to three periods: This is later used as the basis of a rolling algorithm, which is presented in the paper.

The paper constructs the constraint matrix for bundle constraints applied at the various allowed levels. The node-incident matrix obtained after the application of a number of linear transformations is also presented. Two cases are said to arise however, in which the application of bundle constraints in the three period case, will not result in a network structure.

1. If there exists bundle constraints of either type at more than one level.
2. if production constraints are not at the same level as inventory constraints.

Table (2.12): Billington et al. Model

Model summary	Objective Function	Constraint Equation
Billington et al. (1984) **(Variable lead time)**	min: $\sum_{\substack{i=1\\t=1}}^{N\ T} (H_{it}\ I_{it}+C_{ri}\ Y_{it}) +\sum_{\substack{d=1\\t=1}}^{D\ T} (CO_{dt}O_{dt}+CU_{id}U_{id})$ (2.29)	$I_{it-1}+m_i P_{it-L_i}-I_{it}-\sum_{j(i)=1}^{N-1} A_{ij}p_{j(i)t}=D_{it};$ $i=1..N,t=1..T.$ (2.30)
Single product,Multi Facility(assembly),Multi Period. **Holding,production,setup, overtime,** **undertime costs.**		$\sum_{i=1}^{N} (b_{id}P_{it}+S_{id}Y_{it}+$ $U_{dt}-O_{dt}=C_{dt};$ $d=1..D,t=1..T.$ (2.31)
Linear Costs. **Linear programming.**		$P_{it}-qX_{it}\le 0;$ $i=1..N,t=1..T$ q v. large (2.32)

The rolling algorithm presented in the latter stages of the paper becomes exceedingly complex as the number of levels within the product structure increases. An increase in the number of bundle constraints combined with a similar increase in the number of levels often results in a solution which has little or no advantage over traditional linear programming solutions. For the multi-level problem therefore, Zahorik et al. [15], suggests one or two period rolling in order that an opportunity for cost reduction can be found.

The empirical work outlined in the paper deals with the computational efficiency of two linear programming packages, LINDO and MRSX (produced by DEC and IBM respectively), compared to that of the rolling algorithm. Results presented would seem to point to the superiority of the rolling algorithm.

This paper is unique among those reviewed so far in that it transcends the bounds of simple requirements planning, by attempting to incorporate capacity constraints and in so doing, develop a finite loading model.

2.3.2 Billington et al. [16], provides a very general approach to capacity constrained systems [Table (2.8)]. The model developed is for the multi-period, multi-facility, one parent assembly product structure. The final form of the model incorporates set-up costs, holding costs, and under-time, overtime costs within the objective function. The paper tackles the problem of lead-time and lot-size interactions. Lead times are said to be made up of the following:

1. Set-up times
2. Production times
3. Wait time
4. Removal/Transport time

Capacity constraints placed upon facilities will ultimately affect the above, and because of this it is assumed that lead times as well as lot-sizes are variable. The problem then reduces to the simultaneous determination of -

1. Lot-sizes.

Table (2.13): Ho et al. Model

Model Summary	Objective Function	Constraint Equation
Ho,McKenny (1988) (variable lead times)	*Min:* $\sum_{i=1}^{N}\sum_{t=1}^{R_i} (H_{it}I_{it}+C_{it}P_{it})$ (2.33)	$I_{it-1}-I_{it}+p_{it}-A_{ij}P_{j(i)t+L_j(i)}=D_{it}$ $i=1..N,t=1..R_i.$ (2.34)
Single product, multi period ,multi facility(assembly). Production,Holding costs.		$P_{it}=0,i=1.N,t=1.L_i$ $I_{10},I_{iR_i}=0,i=1..M$ $P_{it}\geq0,I_{it}\geq0,1=1..N,t=1..R_i.$ (2.35)
Linear Costs Linear Programming.		*(Capacitated form)* $\sum_{i=1}^{N} E_{id}P_{it}\leq U_{dt};$ $d=1..D,t=1..T.$ (2.36)

2. Lead times.

3. Capacity utilization.

The problem is formulated as an integer-linear program. Billington et al. [16] states that the model can be solved using leontif substitution systems when only the material balance constraints are applied. As yet however, no solution has been found for the global problem. Both

1. Decomposition
2. Lagrangian relaxation

have been suggested as possible solution techniques.

As with all MRP models, demand (in discrete time periods) initiates production. Changes in capacity however due to breakdowns, lack of personnel etc. are not provided against within the model. Billington [16] suggests three methods which might provide against any unforseen changes.

1. The objective function could be modified to minimise a discounted sum of slack production
2. Reduce the RHS (right-hand side) of capacity constraints to below its known limit, thus keeping some in reserve.
3. Build buffer inventory into the master production schedule.

The latter half of the paper deals with the possible reduction of the ILP. The crux of this procedure lies in the definition of a constrained facility.

> "A facility upon which the time limit is likely to be a binding constraint, often enough and for a long enough duration to cause a scheduling difficulty".

Unconstrained facilities would be scheduled for in a lot-for-lot fashion, once the constrained facility is determined. The following two rules must be adhered to, in order that the compression of the ILP is successful.

1. Variables relating to all items with significant set-up costs, and/or items produced on a constrained facility must remain.
2. Variables belonging to items that
   a) share a common item
   b) eventually form part of type 1 items must also remain.

Table (2.14): Zahorik et al. Model

Model Summary	Objective Function	Constraint Equations
Zahorik et al. **(1984)** **(Const lead Time.)**	min: $\sum_{\substack{k=1\\i=1\\t=1}}^{MNT} (C_{kit} P_{kit} + H_{kit} I_{kit})$ (2.25)	*Conservation of Flow:* $A \ E_k = b_k ; k=1..M$ (2.26)
Multi product multi facility (series) multi period. **Production,holding costs.**		$\sum_{k=1}^{M} P_{kit} \le \overline{P_{it}}, \ \forall_{it};$ $\sum_{k=1}^{M} I_{it} \le \overline{I_{it}}, \ \forall_{it}.$ (2.27)
Linear Costs. **Linear programming.**		$0 \le P_{kit} \le L_{kit};$ $0 \le I_{kit} \le W_{kit}.$ (2.28)

The rationale behind these two rules is that items produced on constrained facilities will have lead times which depend upon the capacity available. Items with large set-up costs must also remain to allow batching.

The compression itself is done in two phases. Firstly any reference to items which will be subsequently used by Lot-For-Lot items all the way to End-Item level are eliminated. The second phase elimanates any Lot-For-Lot items which don't share common inputs. The resultant product structure is substantially reduced. By isolating lead times and lot-sizes, as being two of the major contributors to a manufacturing system's overall performance, the model secures the foundation for a good MRP model. Lead times are not, as generally assumed, instantaneous, but may be thought of as function of work-in-progress, which in turn is dependent on time accumulated during processing.

2.2.3 Ho and McKenney [17], present a short paper, the general theme of which is that although the presented models are not network linear programs, they possess an interesting network property, namely that they can be triangularized by successive applications of linear transformations. The models presented, introduce both production and holding costs, and the constraint matrix is made up of material flow equations in the usual fashion. The equations however are slightly modified by the introduction of dynamic or varying planning horizons for the various facilities. [Table (2.13)]. Production and inventory variables for a particular facility are constrained to occur within the planning horizon span at that facility. The calculation of this horizon is based on the planning horizon and lead time at a parent facility.

Ho et al [17] suggest that triangularity property of the constraint matrix means that the operations of the simplex method would ultimately be reduced to a set of back substitutions and hence greatly reduce processing time. He also suggests formulating the problem as a network with side constraints would result in an optimal solution.

The second model presented, is similar to the first with the exception of a further constraint which limits the total capacity available at each facility. This model is referred to as the multi-product finite loading model. Ho et al [17] suggests Dantzig-Wolfe Decomposition as being a possible solution procedure, once advantage has been taken of the triangular nature of the basis.

2.2.4 Prentis and Khumwala [18], present a multi-period, multi-facility, general assembly model [Table (2.14)]. The objective function includes both production, carrying and set-up costs, and has the capability to handle cost breaks, in both production and purchasing. It is said to be piecewise, both concave and convex, (non convex) which excludes any linear programming from directly solving the problem. The model is the most comprehensive to be found in literature, and is solved using a complex branch and bound technique. The technique is explained in the paper and an example problem solved.

Prentis compares computational results, using his branch and bound method, with a number of other well known lot-sizing techniques, over a variety of demand patterns. It is found that in all cases the branch and bound technique performs better than any of the other methods.

2.4 JIT SIMULATION MODELS

2.41 Introduction

Unlike the techniques of analytical mathematics which have been used to solve a variety of problems for hundreds of years, simulation is a relatively new method of problem solving made available by huge advances in the processing capability of computers. In recent years, simulation is being used more and more in the manufacturing field to investigate various systems' performance under a variety of operating conditions.

Within manufacturing, simulation techniques would appear to have found a particular application in the relatively new areas of JIT production and flexible manufacturing, as a means of explanation as well as experimentation.

This section of the survey provided a brief review of some papers which develop simulation models, with application in the Just-In-Time environment either as a means of experimentation or as learning tool for others.

2.4.1 Huang et al [19], present an interesting paper, investigating the effects of variances on system performance using the following parameters.

1. Kanban cards at each stage.
2. Processing times at various stages.
3. Demand rates.
4. Combinations of the above.

The paper initially provides a very comprehensive explanation of the operation of a two-card Kanban model, and its translation into a Q-GERT simulation model. The actual model simulated is a variation of a 3-line, 4-stage general assembly model, described in Chapter 8.

The first experiment conducted, investigates the effects of various processing time distributions (all work-stations having the same processing time) for systems with both 1 and 2 Kanban cards. Performance parameters include overtime, production rate, and input and output buffer inventory levels at final assembly. The second experiment examines the effect of bottleneck located at various positions along as assembly line, and the third experiment examines the effect of demand distribution variablity. The interactive effects of demand and processing time variability are also investigated. In each case, performace parameters are as described above.

The main conclusions are as follows:-
In order to effect a transfer to JIT production, large increases in overtime must be expected, in an effort to reduce process time variation. An overtime ban would only serve to increase work-in-progress and an inability to meet the demand schedule: Bottle-necks can not be tolerated within a JIT system, because their effects can not be counteracted by system parameters such as the number of Kanban cards: JIT production can not be operated effectively while there is a degree of variability at demand level.

2.4.2 Ebrahimpour et al [20], take a slightly more indepth look at the effect of Kanban card usage on work-in-progress inventory. The model presented is that of a two-stage production line. The model is coded using the DYNAMO simulation language.

Two types of demand patterns are under investigation, that of cyclical demand, and constant growth demand. Simulation runs are carried under both these conditions, firstly to quantify the degree to which production can keep up with sales, and secondly to investigate the rate at which the Kanban cards can be reduced, without adversely affecting production.

The main conclusion of the paper is that under both sets of operation conditions, the reduction of the Kanban cards operation within the system does not cause production to lag behind sales, but does cause a significant reduction in work-in-progress inventory. It was also found however that there is a point beyond which further reduction of the cards does affect production.

2.4.3 Schroer et al [21], use a Kanban production model to investigate the operation ot the SIMAN simulation package. The paper appears to place greater emphasis on both the performance of SIMAN and the development of the simulation model for an assembly line consisting of two assembly cells that on the actual model performance. The paper concentrates on the levels of work-in-progress at various points withing the system, both one and two kanban card operation were investigated.

The paper is of note mainly for its use of the Siman language. No conclusions are made on the basis of results presented.

2.4.4 Sarker et al [22], use the SIMAN simulation language to investigate the effect of a number of umbalancing methods on a number of system performance parameters, - queue lengths, machine utilizations, waiting time, cycle times, and finally production rates. The actual simulation model consisted of a six-stage assembly process.

Four unbalancing methods were analysed. The first, referred to as the see-saw effect, involved isolating three stations, and simultaneously increasing and decreasing the processing times of the first and third stations respectively. The second and third methods involved the creation of a processing time bowl over three and five stations, (i.e. the middle stations have lower-concave and higher-convex processing times). The effect of a change in only one stage, in one line is also investigated.

The main objective of the paper is to evaluate the operation of the various imbalancing methods and in so doing, afford production managers useful insight into the implication at the various stages so that they can adjust system parameters accordingly. The various conclusion pertaining to each and every system configuration are too numerous to mention here, however the paper does prove that a balanced configuration ensures optimum system performance.

The paper concludes with a similar observation to that of Huang et al [19], - that Western manufacturers cannot immediately transfer to JIT production without evaluating the various requirements of the new system and making the appropriate modifications. Simulation techniques are very useful in this respect.

2.4.5 The paper of Browne et al [23], presents quite a complex simulation model, which has application in the testing of control mechanisms for flexible assembly systems.

The actual simulation model which is coded in SLAM II consists of a 5 station assembly line, each station having a maximum of 5 feeder stations, although this number may be varied. A total of our individual products may be produced on the mode. Two different types of sequencing methods are available: an MRP type sequence, and a Kanban sequence, the object of which is to develop uniform work loads on the line. The model allows the modeller to choose from a variety system of the system performance parameters, such as processing times, etc. Various limitations and assumptions are listed in the paper.

Unlike the previous papers reviewed, this model is more complex, being produced and developed not only for use bt the developers themselves, but also for other experimentors who are interested in simulation results but not in actual model building. The last section of the paper discusses an experiment which investigates the effect of batching and set-up times on JIT production.

The main conclusion from the experimental section is that failure to reduce the set-up time, while reducing the batch size causes reduction in the production rate of the system.

2.2.6 The paper of Villeda et al [24] is similar to that of Sarkar et al [22], in that the area of investigation is unbalanced production lines. There exists two notable differences however. Firstly, Villeda [24], is interested in both mean and standard deviation variances, and the range of variation is much smaller than that of Sarkar et al [22]. Secondly, each of the system configuration investigated may be referred to as bowl shaped. The simulated model consists of a three line assembly system, with three work station at each line.

The first experiment isolates the unbalancing method with the greates potential to increase the systems performance. All the experiments are then carried out with reference to this method. Variation in the standard deviation of the processing times are investigated for systems operating with one and two card Kanbans. Performance measures include production rate, mean utilizations, mean wait time at final assembly etc. The third set of experiments investigates the introduction of variability at final assembly. Again the same performance measures are used.

The paper of Sarkar et al [22], demonstrates that when the unbalanced range is large, and the increments in processing times are also compariably high, balanced system will always outperform an unbalanced one. Velleda et al. [24] however, isolated a small unbalance range, where unbalanced systems outperform balanced ones for all the umbalancing configurations used.

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CHAPTER 3

PRODUCTION SYSTEMS

3.1 INTRODUCTION

In the words of Goldratt and Cox [25] the primary aim of any manufacturing concern is to make money. Secondary aims, which complement this include:

1. To satisfy customer orders on time, and with least costs.
2. To maintain/obtain a good market share.

In order to satisfy these objectives, a manufacturing firm, requires a formal structure within which it can seek to operate successfully. Many books, have been written, attempting to describe this formal structure, and although, the basic principles and concepts, never change, literature shows that the actual description of this structure, is subject to the individual's interpretation.

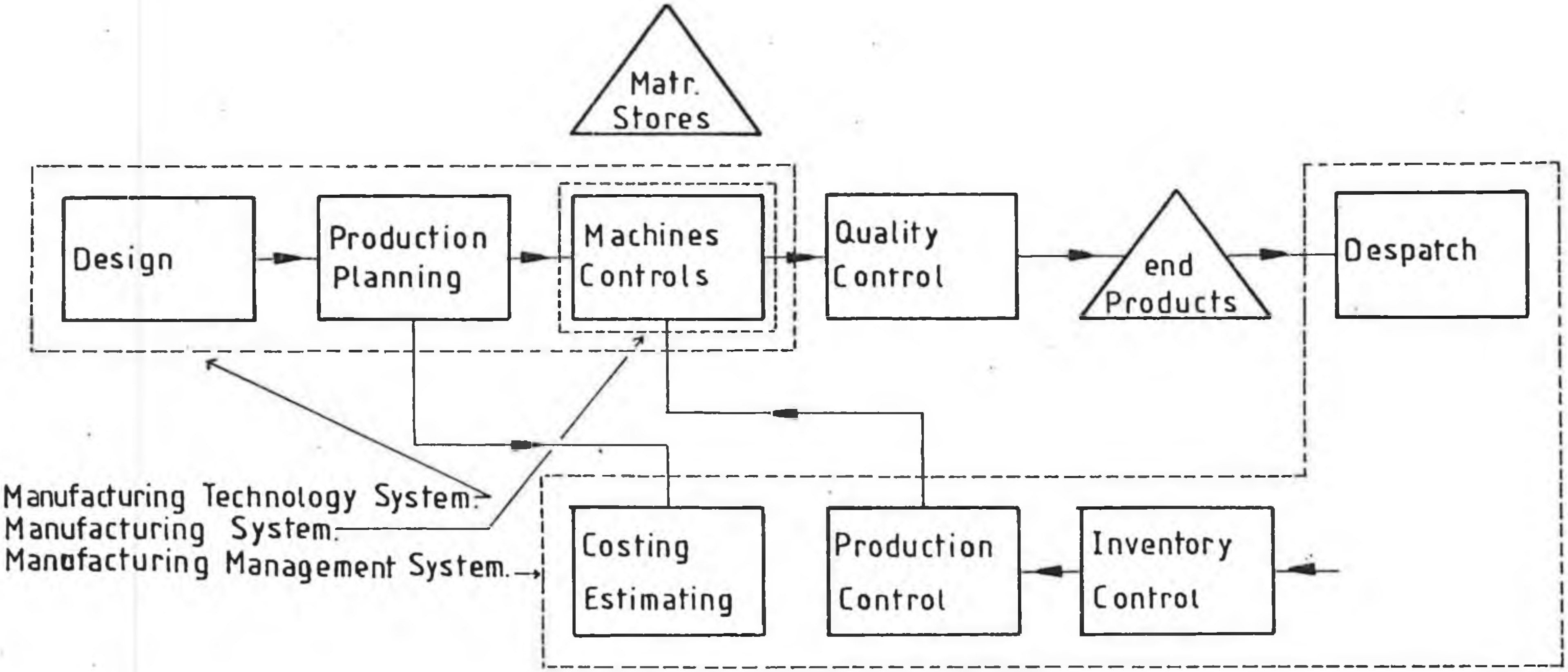
3.2 IDEALIZED STRUCTURE OF MANUFACTURING ORGANIZATION

An idealized interpretation of this structure is shown Fig (3.1a). This figure shows the overall structure within which two subsystems operate, namely:

1. The manufacturing technology system.
2. The manufacturing management system.

It is within the manufacturing technology system, that, the origins of the whole structure lie, with the design function. Once product designs have been decided upon, the production planning function is called upon, to create the routing system necessary to ensure the correct manufacture of the product according to the design specifications. Once this route has been decided upon, the relevant data is then given to the costing function, within the manufacturing management system, to evaluate production costs for the product, on the basis of routing, times, and process times etc. imparted by the production planners. Production costs, are traditionally derived from a division of costs, into three categories [26,27],

1. Direct Labour Costs.
2. Direct Material Costs.



Idealized Structure of a Manufacturing Organization. Fig.(3.1a)

3. Overhead Costs.

although, advances in such areas as automation, inventory control, are rendering this method of costing a "Dinosaur". Direct labour used to account for 50% of prime costs (Direct Labour + Direct Material), now it may account for as low as 2-3%, with the result that time spent, on trying to reduce, labour costs, would be much better spent, focusing on inventory or overhead reduction. A new method, of costing has developed, termed throughout accounting, based on two concepts [28].

1. A factory is not a collection of individual resources, but an integrated system of processes and machines, and as such the term, -total factory cost, -refers to all fixed costs originating in the factory.
2. Products on their own are neither profitable or unprofitable, it is the rate at which the product contributes money that determines relative product profitability.

Once costs have been decided upon, the production control function, in the manufacturing management system, is required to:

> "Plan direct and control, material supply and processing activities, of an enterprise, so that specific products, are produced, by specified methods to meet an approved sales program, these activities being carried out in such a manner that the labour, plant, capital available, are used to the best advantage".

Which is essentially equivalent to saying of the production control function, - that it guides material flow, through the material flow system, as created by production planning - This material flow system, consists of the route a particular product takes as it traverses the manufacturing system.

As material, flows through the manufacturing system, monitored closely by production control, stock, in terms of Work-In-Progress (WIP) is generated. The inventory control function, is required to maintain, this type of stock, and both raw materials, and finished products at a required level. Inventory control was often thought to be secondary to production control, [29] in that, production control is administered, with the aim of keeping inventory at an optimum level. The realization of the enormous benefits of a reduced inventory level has afforded it a higher status than previously.

Quality control is somewhat, of a misnomer within the manufacturing structure, fitting neither into the manufacturing management system, or into the manufacturing technology system, but at the same time being part of both. With the emergence of the Just-In-Time and Total Quality Control, manufacturing philosophies, a certain shift in emphasis in the role of quality control has also taken place, with the quality control procedures being built into the manufacturing process as much as possible, and making quality managers, responsible, only to the top level in the hierarchal management structure.

The final function of the manufacturing management system is despatch, - the actual removal of goods from the factory and transportation to the customer.

3.3 EXAMPLES OF MANUFACTURING ORGANIZATION STRUCTURE

As mentioned previously a wide range of literature is available, describing this formal structure. Burbridge [29], refers to this formal structure as a productive system, within eight management functions operate, namely.

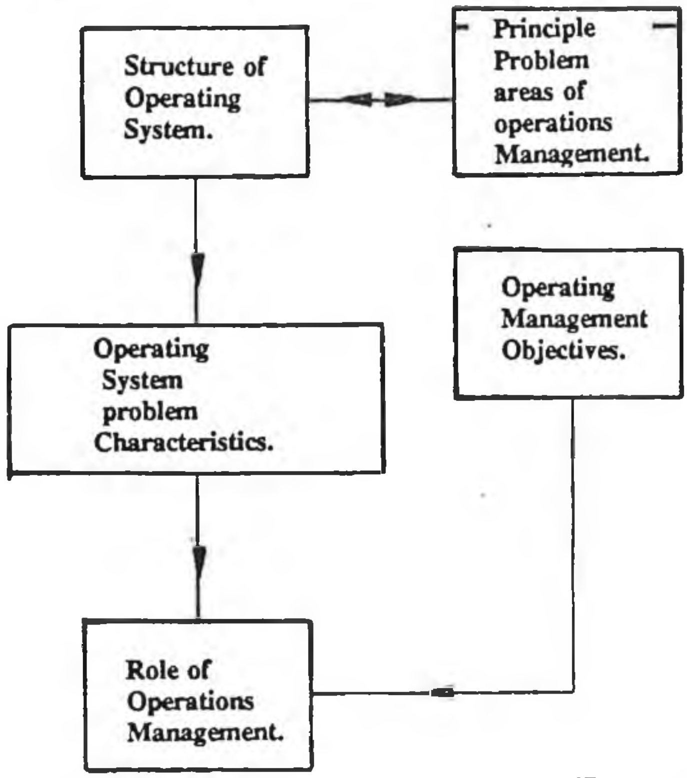
1.	Financial	4.	Personnel	7.	Design
2.	Marketing	5.	Purchasing	8.	Secretarial
3.	P. Planning	6.	P. Control		

With this structure, production planning and design, and both the production control and financial functions are closely related.

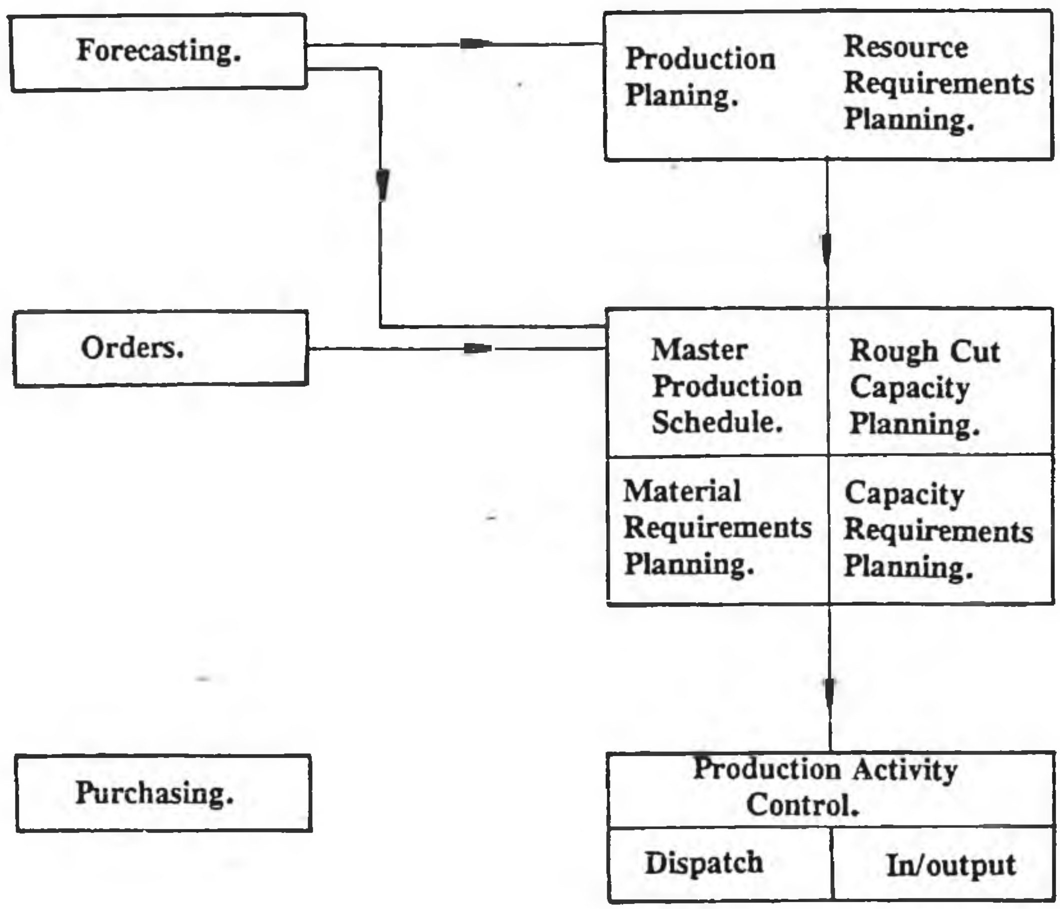
Wilde [6] speaks of operating systems:

> "An operating system, is a configuration of resources combined for the function of manufacture, transport, supply or service".

Operations management therefore, is concerned with the design and operation of the system. Operations management is divided into two main areas, design and planning,



FrameWork of Concepts for Operations Management. Fig. (3.1l



The Hierarchy of a production Management System. Fig.(3.1d).

and, operations planning and control. Fig. (3.1b) provides some insight into Wilde's ideas.

Groover [26], divides factory planning into four sections:

1. Business Functions
2. Product Design
3. Manufacturing Planning
4. Manufacturing Control

Information flows within this structure are shown in the diagram (Fig. (3.1c)).

Browne et al [5], speak of production management systems, emphasizing the hierarchial nature of the structure. Production activity control is forwarded, as that element of the production management system closest to the production process. Fig. (3.1d) identifies the hierarchial relationship of the various elements within the structure.

Depending on which book you choose, the type of structure, designated to the manufacturing firm will vary, in both terms applied and groupings. The underlying functions however don't change, because any manufacturing organization requires the same undelying functions in order to operate. The essentials of production control, production planning, inventory control, etc. will always be evident.

3.4 TYPES OF PRODUCTION

The degree of importance afforded to the various functions of organisation structure, is dependant to some extent on the type of production employed in the plant. Classification of production types, is also an area, which is subject to a variety of interpretations.

Wilde [6], identifies three production types, namely:

1. Continuous Manufacture
2. Repetitive Manufacture
3. Intermittant Manufacture

A continuous process may run, 24 hours a day, 365 days a year, and may itself be of three types.

1.	Flow	-	Chemicals/Cement/Tin Cans.
2.	Seasonal Flow	-	Frozen Vegetables.
3.	Flowline	-	Motor Cars, Television Sets Etc.

A repetitive process, is similar to flowline, in that products are processed in lots, each product being subject to the same sequence of operations. It is defined by Hall [31] as:

> "Fabrication, machining and assembly and testing of discrete standard units produced in high volume, or of products assembled in volume from standard options. It is characterised by long runs or flows of parts. The ideal is a direct transfer from one work centre to another."

An intermittant process is characterised by small lots, and possibly single products, made in response to customer orders.

An alternate classification, offered in [5,26] is:

1. Mass Production.
2. Batch Production.
3. Jobbing.

Mass production, is concerned with the continuous, specialised manufacture of identical products (similar to flowline). Production rates are usually very high, equipment highly specialised, and usually dedicated to one product.

Batch production is intermediary between mass production and jobbing production is carried out on small batches, medium size production runs. Each batch being fully processed, before the next operation takes place. Equipment used, must not be too specialised, in order that variations in customer requirements may be met (MTS).

Jobbing, is characterised by low volume production runs, with a high variety of products. This necessitates flexible equipment, and a highly skilled work force. Products always manufactured against customer orders.

Burbridge in [5], offers another classification of production types:

1. Implosive - Iron Foundry.
2. Process - Cement, Chemicals.
3. Explosive - Electronic Assembly.
4. Combination

Implosive production is typified by products, whereby small varieties of different materials, produce large variety of products. Process types occur where small variety of raw material produces a large variety of products. Explosive systems occur, when, large varieties of raw materials produce small product range.

Irrespective of the type of classification used, as the variety of raw materials, and product complexity increases, the greater the input required from the various functions involved. Production control is an easy concept, when, the variety of parts involved is small, however, as the variety increases production control, becomes more complex.

3.5 PRODUCTION CONTROL

The production control department, is ideally the link between other departments and the actual manufacturing process. It processes all the information necessary (Table 3.1) form the various departments, in order to translate customer orders into viable production schedules.

Scope of Production Control

"Production control, describes the principles and techniques used by Management to plan in the short term, and control and evaluate the production activities of the manufacturing organisation". Browne [5].

In an effort to comply with the above definition, the production control department will perform the following activities:

1. Inventory Control: MRP.

TABLE (3.1): Information Flow To Production Control

Information Fed to P. Control	Source	Department
Production Required	W/O	Sales
Delivery Date	W/O	Sales
Quantity Required	W/O	Sales
Manufacturing Method	R/C	Production Planning
Times, Sequences of Operations	R/C	Production Planning
Material Required	B.O.M.	Design
Material Availability	Inv. Rec.	Inventory Control
Capacity Available	—	Production Planning
Machine Maintenance	—	Maintenance

W/O: Works Order

R/C: Route Card

2. Preparation of Working Documents (W/O, R/C, J/T, D/N).
3. Loading, Scheduling.
4. Material Movement Monitoring.
5. Despatch.
6. Progressing.
7. Evaluating Results.
8. Forecasting.

Planning

9. Capacity Planning.
10. Master Scheduling.
11. Labour Planning.

All activities being based on information fed from other departments.

3.6 PUSH AND PULL

3.6.1 In recent years a certain amount of controversy has arisen over the correct application of the terms push and pull to production control systems.

Orlicky [32], initiated the debate in 1975, by proposing that material requirement planning (MRP) simultaneously gives rise to both push and pull operation modes. The push mode, is that of the formal order launch, which by necessity relies upon possibly inaccurate data - inventory status and otherwise. This gives rise to the informal pull or expediting mode, in order to ensure that the due date coincides with the time of actual need.

Schonberger [33], acknowledges that a degree of informality exists within a pull mode, but says that in reality, a push system is a schedule based system, which pushes production people into making the parts, and then pushing them onward.

A pull system relies on the assumption that customer orders make up the final assembly schedule, and parts not on hand are pulled through to meet requirements.

In order to classify two of the commonly recognised pull systems under the heading push and pull, schonberger considers two activities - production, and material handling/delivery. He says of dual card Kanban - Pull system of production combined with pull system for delivery. Single card Kanban however, used a pull system for material delivery but production is initiated by a production schedule and therefore may be recognised as a push system.

Browne [5] adopts the more traditional form of classification: Material requirement planning logic is that of push, - "Action is taken upon anticipation of Need" - Kanban Logic is that of Pull- "which requires action upon request."

Papers such as Rice and Yoshikawa [34], which refer to both MRP and Kanban as Pull systems because they both aim to be Just-On-Time, represent a greater attempt to play with words than finally lay to rest the debate, and proceed with the important issues to generate and effectively execute valid schedules. Monden [35], summarises the previous discussion by saying that Push systems require that parts be processed in accordance with the preceeding work centres requirements, and a Pull system in accordance with the succeeding processes requirements.

3.6.2 Within manufacturing circles today, two major manufacturing philosophies are at work. The first of these is the computer based manufacturing resourse planning (MRP II) system the core of which is the push driven material requirement planning module. The second philosophy is that of Just-In-Time (J.I.T.), the core of which is the pull driven Kanban. Much is made of the fact that the J.I.T. philosophy is not computer-based. This however is a fallacy, and although Kanban itself does not utilise computers to initiate production or monitor material flow, computers play an important role in establishing the necessary conditions to make Kanban work (i.e. production smoothing).

The material requirement planning module, utilizes requirement data, lead time data, inventory status data, bill of material data to generate production schedules usually in weekly time buckets for each and every component, sub assembly and end item. These may or may not contain a degree of forecasting. In order to initiate production, within the JIT environment, one schedule is produced daily this schedules refers only to final assembly items and represents firm customer orders. Within the MRP push environment production starts at the raw material end, and providing lead time data is correct, will arrive on time at the next process. The pull environment requires that a small amount of stock is available at each and every work centre. If a required item is not available at final assembly (station M), then the required quantity is removed from station M-1, this also sets production at stage M-1 in process driven by the need to replenish the removed stock.

Manufacturing resource planning carries out the scheduling function with no recourse to such ideas as group technology (GT) or product families. Batch type manufacture is the most common type, and a production line may be making the same items all day. Kanban relies heavily on G.T. and the adage "Make a little bit of everything every day" describes the production scheduling algorithm for the final assembly, also referred to as production smoothing. Repetitive manufacturing, which has less product variety but a greater volume than batch production, but is not quite classified as mass production is usually associated with Kanban and JIT production.

3.6.3 As stated previously, MRP relies heavily on up-to-date and accurate information, if this is not forthcoming the formal system breaks down. Individual process lead times are therefore very important to the success of MRP. With Kanban however, individual process times and ultimately overall thruput times vary in accordance with the loading. If the loading is high workers from surrounding work centres may be brought in and idle machines used to increase the scale of production and reduce thruput times. Conversely if the loading is light less machines and less workers are utilized, and so lead times expand. Therefore instead of lead times helping to drive the system, the system determines the lead times.

TABLE (3.2a): The Usage Effect of Various System Operating Variables

	JIT (KANBAN)	MRP II (MRP)
Lead Times	Lead times of individual processes not utilized in generation of schedule.	Lead times, very important in in the generation of valid schedules - inaccurate.
Work In Progress	Very low, dependant on the number of cards in the system.	Very high, dependant on schedule specifications.
Batch Size	Very small, - reduces overall thruput time for individual items.	Very large - to take advantage of set-up times.
Machine Utilization	Very low - due to such factors as small batch size, small wip etc.	Very high, due to large levels of inventory, waiting to be processed.
Set-up Time	As short as possible due to unit batch production.	Large set-up times.
Overall Cycle Time (CT)	Variable - depending on the rate of loading. High Loading - Short CT Low Loading - Long CT	Usually very long - greater than cumulative process times due to wait, queue, time etc.

TABLE (3.2b): Comparison of Two Manufacturing Philosophies

	JIT (KANBAN)	MRP II (MRP)
What Initiates Production	FINAL ASSEMBLY SCHEDULE	MULTIPLE SCHEDULES FOR - EACH WC
How is Production Flow Achieved	BY SIGNALS FROM DOWN STEAM WC	SCHEDULE
How is Material Movement Achieved	BY SIGNALS FROM DOWN STREAM WC	PUSHED ONTO NEXT WORK CENTRE
What is Logical Flow of Requirements	ASSEMBLY TO RAW MATERIAL	RAW MATERIAL TO ASSEMBLY
Type of Production Most Suited	REPETITIVE	BATCH TYPE

By their very nature, requirement planning systems require a lot of work-in-progress. The acceptance of long set-up times adds to this problem. Pull systems however, which concentrate heavily on set-up time reduction can incorporate a very small batch size. The average work-in progress within the system, is a function of the production system itself, and is often reduced to a value just above the point at which it would begin to impede production.

Machine utilizations figures are often quite small using Pull systems when compared to push. This is due to a number of factors. Firstly, overall requirements are lower, due to the lack of forecasting within the production schedule. Secondly, smaller batch sizes, reduce machine utilization. Thirdly, Pull systems only produce what has been removed, from the system in meeting requirements. The predominant manufacturing philosophy presently in use in the west is that of manufacturing resource planning. This is slowly changing however, as manufacturers, aware of the many benefits to be gained from adopting pull type systems, are beginning to implement certain pull system elements.

CHAPTER 4
INDUSTRIAL SURVEY

4.1 INTRODUCTION

4.1.1 Review of Industrial Policy

Ireland finally gained independence in 1922. By that time however industry in the state had been decimated, with only 4.3% of the population engaged in manufacturing.

The country's industrial development from that time to the present day may be split into two fairly distinct phases. The first, based upon the belief that Ireland could be made into-

> "A self-contained unit providing all the necessities of living in adequate quantities for the people residing in Ireland" - Lemass [36].

was inward looking in nature, encouraging a type of import substitution industrialisation. The main weapon being the indiscriminate use of protectionist policies. By 1950, after ever increasing balance of trade deficits, it became apparent that a new approach was required, if indigeneous industry was to break away from its stagnant position in the technically mature end of industrial markets, into activities, where barriers to entry were much greater.

The initiation of this new approach was marked by the establishment of the Industrial Development Authority (IDA), in 1949, followed closely by that of The Irish Export Board (CTT), and the Grants Board in 1952. Attracting foreign industralists, advising and encouraging on exports, and supplying non repayable grants, were the primary functions, of these boards. The introduction of export tax relief (replaced by low rates of corporate tax) and various finance acts, ensured that by 1960 the transformation to export orientation was complete, and that Ireland had become a favourable shore for foreign investors. Ireland's subsequent membership of the

European Economic Community (EEC) in 1973, necessitated the introduction of free trade, but simultaneously provided access to a large market.

4.1.2 Barriers To Entry For Late Developing Countries

As a late industrializing country, indigenous firms hoping to compete in a wide range of industrial markets, may face unsurmountable barriers to entry. The most obvious of these barriers are economies of scale, arising from the fact that the average costs of well established firms decrease as the scale of production increases. Conversely a small company starting off will experience barriers due to small production scale, and hence higher costs.

Larger firms, also have product differentation advantages, arising from brand names, adverstising quality etc. Capital requirements, proprietory technology, learning curves, and external economies - (suppliers, skilled labour, local market), all combine to present a significant challenge for any small company thinking of entering a particular market.

The IDA's policy of attracting foreign investment, has provided Ireland with the opportunity to participate (albeit by proxy) in those markets whose entry barriers are of such great magnitudes that small indigeneous firms have failed to penetrate them to any degree. The electronics market is one of these areas.

4.1.3 Present Day Statistics

At present the Irish Electronics Industry accounts for nearly one third of annual exports worth about £4.2 billion, and employs 27,000 people, in 250 firms [37]. Only 45 of these companies however are indigeneous and only one of these appears in the list of the top one hundred indigeneous firms [36].

4.1.4 The IDA and Foreign Investment

The tradition of direct foreign investment began in the 1930's, consisting mainly of English investors, producing for the local market. It was not until the 1950's that foreign investment became more export orientated.

The IDA promotes Ireland worldwide as a site, ripe for potential investment. This often proves difficult for two reasons. Firstly, manufacturing firms generally, are not anxious to relocate, in order to take advantage of cheap labour etc. Secondly, for each pool of investors interested in relocating, a large number of newly industrializing (NIC) or late developing (LDC) countries compete, to act as host nations.

It has been shown in recent years, that foreign investment in late developing countries worldwide, is confined to occur within one of the three following areas.

1. Basic processing of local resources.
2. Technically mature and standarised labour intensive final products.
3. Relatively simple stages within a longer process of production of sophisticated goods.

The bulk of foreign investment in Ireland would appear to fall into the latter two categories. The associated problems are well known: Very little Research and Development taking place; employment concentration within the lower echelons of the educational scale, and by virtue of the previous comment, very little transfer of technology to indigenous industry.

This view of foreign investment in Ireland is reinforced by a survey (1975) by J. Teeling [36], who says that the majority of electronic firms surveyed-

> "Are currently manufacturing satellites, performing partial steps in the manufacturing process. Skill development, and linkages in Ireland have been limited. The electronics industry is a highly skilled industry worldwide but the activities in Ireland's electronic industry do not reflect this."

4.1.5 Why Ireland?

The rapid increase in the numbers of countries competing for foreign investment in recent years, has required that a potential investor be confronted with slightly more than low labour costs, ease of access to markets, political stability etc. In the wake of competition from countries as far apart as Taiwan, and Scotland, Ireland's continuing ability to attract foreign investment is surprising.

M. Cronin [37], Head of the Electronics Division in the IDA, puts Ireland's success down to availability of skilled labour, low inflationary costs, and finally the tax incentives and the variety of financial aid packages available. Eoin O'Malley [36] however, goes slightly further than this, and says that the internationally recognised efficiency and previous history of such bodies as the IDA and SFADCO, instill a certain confidence among potential investors. Ireland's membership of the EEC also provides insurance against any protectionist tendencies, and guarantees stability. Finally Ireland's historical links with both the UK and USA also helps promote investment.

4.1.6 Ireland and Other Late Developing Countries

O'Brien [38], compares Ireland to both the newly industrializing countries (NIC) in the Far East - Taiwan and Hong Kong and also small developed countries, such as Denmark, and the Netherlands. He finds that Ireland has a significantly higher proportion of foreign multi-nationals, (MNC) than most of these countries. Some of these countries however, have experienced much greater growth in the their indigenous sectors than Ireland.

The reasons for this growth in indigenous development (in many cases where the barriers to entry are high,) is, in most cases due to the successful application of export orientated policies with a certain degree of protectionism. Korea, as far back as 1974, frequently imposed exporting and ownership share policies prior to granting entry permission. The South Korean Government favour loans as a means of foreign investment, which provides the capital while simultaneously allowing the retention of indigenous control. Research and Development (R+D) is widely encouraged, as is the import of foreign technology through licensing. Highly skilled foreigners are engaged to diffuse technological skills/knowledge down though the industrial ranks.

Taiwan, too, has pursued policies of selective intervention with a great deal of success. Industries earmarked for indigenous development, are subject to a variety of tax concessions. The nature of indigenous development in Taiwan is somewhat different to that of S. Korea or Ireland, being state rather than privately owned. Singapore's industrial and development policy, has been rather similar to that of Ireland in recent years in that it has successfully attracted direct foreign investment, with little or no impact on indigeneous development. It has begun however to take need of examples set by Taiwan and S. Korea and is pursuing limited interventionist policies. Hong Kong, unlike Singapore is not as reliant upon foreign owned industries, the foreign industries present however have played significant roles in the development of indigeneous industry via sub contraction. Most of the indigeneous development however exists in either the more technically mature industrial sector - clocks, radios etc. traditional third world industry such as textiles. (Similar to Ireland).

The preceeding discussion would appear to divide late developing countries into two groups, those that have successfully overcome rigourous barriers to entry in terms of indigenous development and those that have failed. The pursuance of traditionally recommended policies for late developing countries generally leads to the latter, while, deviation from these policies through selective intervention would seem to cumulate in a more successful conclusion.

TABLE (4.25) Employment Share of Foreign Multinationals in the Electronics Industry

Ireland	(1983)	90%
Scotland	(1978)	90%
Singapore	(1976)	84%
S. Korea	(1979)	45%
Hong Kong	(1978)	41%
Taiwan	(1981)	40%
Denmark	(1978)	37%
Netherlands	(1981)	13%

4.2 RESEARCH OBJECTIVES

4.2.1 Introduction

It has become apparent in recent years that the policies pursued by the IDA have been unsuccessful in translating the high degree of direct foreign investment to an equable growth in indigeneous industry. The reasons for this are manifold, and may be dealt with on two broad levels, namely on an economic, and operating level. In terms of operations O'Brien [38] proposes that

1. The reluctance of multinationals to engage in R+D in the host country.
2. The reluctance of MNC to improve production/operation processes in the host country.
3. Little transfer of skilled labour to indigeneous companies.

profoundly effects both the development and improved competiveness of indigenous and multinational firms alike. MNC can and do receive help in upgrading production and operational processes from parent companies. Indigenous firms would hope to learn from established companies. Where this is not feasible however it may be possible for these firms to enlist the aid of Universities.

The following study was carried out to assess the need for a University support group, to upgrade and monitor the development of inventory control systems within Irish Industry, and in so doing reduce the enormous constraint placed upon indigenous electronic companies as they try to enter markets where barriers to entry can be very high.

4.2.2 Research Objectives

The main objectives of this study are:

1. The classification of the Irish electronics industry sector according to, type of products, type of production, production volume, company size, etc.
2. To identifying the common problems and challanges related to the electronics industry sector, with respect to their inventory control systems, in particular

MRP implementation.

3. To identify underlying conditions required to make JIT implementation a feasible proposition for smaller Irish companies.
4. To assess the feasibility of providing technical information and the assistance with implementing the JIT production concept to these industries.

4.3 RESEARCH METHOD

4.3.1 Introduction

In order to carry out the research objectives described a survey questionnarie was designed and circulated among one hundred electronic and electrical companies with manufacturing outlets in Ireland, which were chosen from two lists. One supplied by the Industrial Development Authority (IDA), and the other by Coras Trachtala (CTT) the Irish Export Board. The companies were selected purely at random, irrespective of company size, ownership or demographic situation. Of the original 100 surveys sent out, only 44 were returned completed. Two companies replied in writing, declining to participate in the survey, with the remaining 54% failed to reply.

The questionanaire consisted of 50 questions subdivided into six major groups concerning manufacturing, MRP systems, JIT and their implementation aspects. On consulting the marketing department, at Dublin City University, it became apparent that the normal response rates in similar surveys are approximately 33%, and 44% was deemed respectable. No follow-up phone calls were made during the survey, although previously, each company selected, was contacted to find a contact name within the company.

4.3.2 Survey Questionnaire

The survey was designed to cover six major areas [Appendix (1)].

Part A:	Company Description
Part B:	Description of MRP System Status
Part C:	MRP Benefits and Costs

Part D: Implementation Problems

Part E: Implementation Approach

Part F: JIT Elements Implementation

4.3.3 Nature of the Response

All returned questionnairs were completed correctly, with the majority of the questions answered. 11% of the questionnaires returned were from companies, which do not have formal MRP systems, although in all cases computerization of individual elements was evident. It is also interesting to note that 4% of respondants were in the process of installing formal systems, and as a result found it difficult to complete sections, C,D and E.

The remaining returns were in general completely answered, although some of the individual questions were left unanswered. For the purpose of analysing the data, unanswered questions were treated as voids.

4.4 SURVEY RESULTS

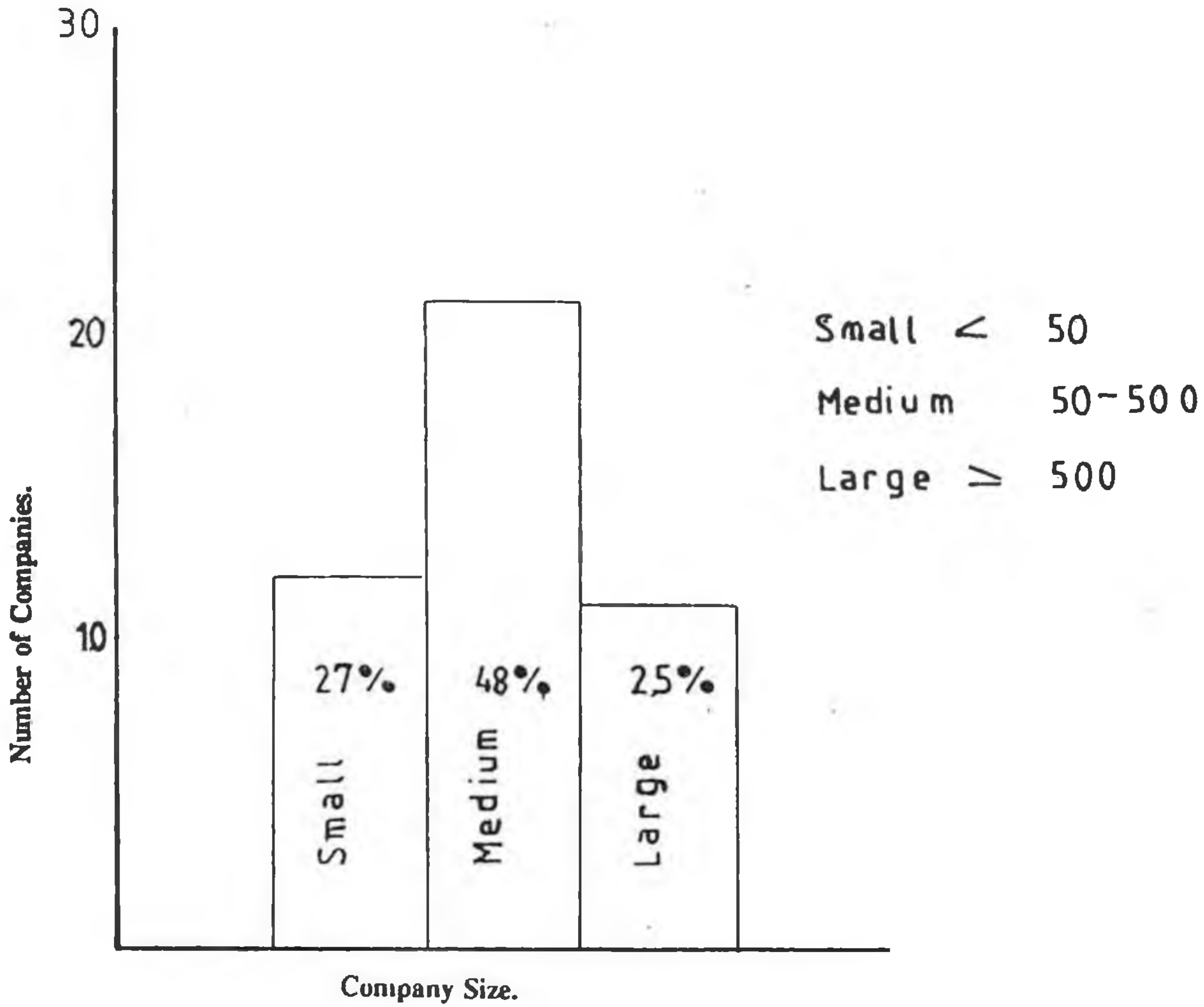
4.4.1 Company Description

This initial section of the questionnaire, was designed to provide information regarding the respective participants, which may be used in later stages to both classify data and establish a broad profile of the companies involved. This profile will serve to ascertain the strengths and weaknesses of the various company sub-sections involved, and allow the analysis of results in relation to the requirements necessary for successful participation in international markets. The results obtained in this section are discussed under the various sub-headings found in the survey's questionnaire.

Company size

Each respondant was asked to provide information regarding the number of people the company employed. This information was then subdivided into three categories.

1. Small <50



Statistical Variation in Company Size for the Group of Companies Surveyed. **Fig.(4.1)**

2. Medium 50 - 500

3. Large >500

Twelve companies, (27%) fell into the first category, twenty one companies (48%) were classified as medium, while the remaining eleven companies (25%) fell into the large company bracket. Fig. (4.1) demonstrates the statistical variation in company size for the group of companies surveyed.

All forty-four companies provided single plant data in answer to this question. The average number of employees was found to be 267, with a standard deviation of 305.2 and a range from 13 to 1,350. It is evident from the graph that the approximately 50% of companies in surveyed fall into the medium size bracket, with the small and large companies obtaining a fairly equal portion of the remaining percentage. This is reinforced by a median value which falls into the medium sized bracket.

<u>Industry Type</u>

Industrial surveys which have been previously carried out conclude that there is a wide range of companies operating within Ireland, in terms of industry type. These types were loosely defined to fall within the following groups.

1. Electronics and Computers
2. Electro-Mechanical (Industrial)
3. Electro-Mechanical (Consumer)
4. Electronic Components

Respondants were asked to decide which group best described their product(s). The analysis of results obtained, led to the distribution shown in Table (4), which includes classification type, and both number and percentage of respondants which fall under that classification.

TABLE (4.1): Number\% of Companies Falling Within Each Category.

Product Description	No. of Companies	%
Electronics and Computers	15	34%
Electromechanical (Industrial)	14	32%
Electromechanical (Consumer)	4	9%
Electronic Components	11	25%
Total	44	100%

The electronics and computer sector heads the table with just over a third of all respondants, closely followed by the electromechanical-industrial sector. Consumer products ar the least well represented, with only 9% of companies manufacturing for the consumer market. Electronic component manufacture, is carried out by exactly one quarter of all respondants. Together, electronic components and computers makes up just under 60% of all respondants. The various sectors outlined in the table are listed below together with some of the more common items which belong to the various sectors.

1. Electronics and Computers

   Mini-computer systems, personal computers, microprocessors, large scale computers, control systems, automatic measuring equipment, digital integrators, air traffic control systems, energy management systems, etc.

2. Electro-Mechanical (Industrial)

   Line printers, high speed line printers, matrix printers, power supply units, oxygen analysers, transformers, electric motors, telecommunication equipment, switch gear etc.

3. Electro-Mechanical (Consumer)

   Scales, bathroom scales, hair dryers, electric shavers, fruit mixtures, smoke alarm systems, electric clocks, movie and slide projectors, etc.

4. Electronic Components

Integrated circuits, printed circuit boards, magnetic heads, potentic meters, cable harnesses, discrete electronic components, etc.

Table (4.2) shows a list of the industries and/or products that are included in the group of respondents.

TABLE (4.2): List of Products and\or Industries

1	**Cable Harnesses**
2	**Computers (Min-computers, word processors, personal computers, large scale computers, computers for CAD/CAM use)**
3	**Computer based process control systems**
4	**Disc drive controllers**
5	**Discrete electronic components**
6	**Domestic appliances**
7	**Electronic control panels**
8	**Electric motors**
9	**floppy discs**
10	**Integrated circuits**
11	**Power supplies**
12	**Magnetic heads**
13	**Printed circuit board assembly**
14	**Refrigeration units**
15	**Sensors, electronic controls**
16	**Smoke detectors**
17	**Telecommunication equipment**
18	**Test equipment**
19	**Touch trigger probes**
20	**Transformers**

From the previous table listing the variety of products available, it is obvious that the maufacturing costs of these items are many and varied. Adding storage costs to the already accumulated costs can result in large investments by the manufacturer, with no guarantee of return. When this investment is balanced against the opportunity cost of losing sales due to long manufacturing lead times, the outcome results in a decision to either manufacture to stock (M.T.S.) or manufacture to order (M.T.O.) or both.

Table (4.3) shows the distribution of companies surveyed over these three categories within each category however, the companies are further divided into those companies which have material requirement planning systems to carry out inventory control, and those that do not.

TABLE (4.3): Distribution of Companies Surveyed with Product Type.

	Companies with MRP		Companies Without MR		Total No. Companies	
	No.	%	No.	%	No.	%
Make to Order	20	91	2	9	22	50
Make to Stock	-	-	1	100	1	2
Both	19	90	2	10	21	48

The above table demonstrates that a significantly small percentage of company's surveyed are operating a strictly make to stock policy. 50% of respondants made to order, while 48% pursue the dual policy of both make to order and make to stock. It is interesting to note that the company operating the make to stock policy does not have an MRP system in operation. Tbe other two categories however, are similarly distributed over companies which have MRP and those which do not. Approximately 10% of each category operate without MRP and the remainder with the help of MRP.

Manufacturing Types

Over the past few decades, much of the industry which has been attracted to Ireland, has tended to fall into the assembly bracket. This is generally assumed to require a low standard of skill, and to do little to promote growth amongst indigenous industry.

Respondants were asked to select the term which best describes their type of manufacturing and the results obtained are listed below in Table (4.4). Companies falling within each category, are again subdivided into those companies with established MRP systems and those companies which carry out inventory control manually.

TABLE (4.4): Distribution of Companies Surveyed Over Manufacturing Type.

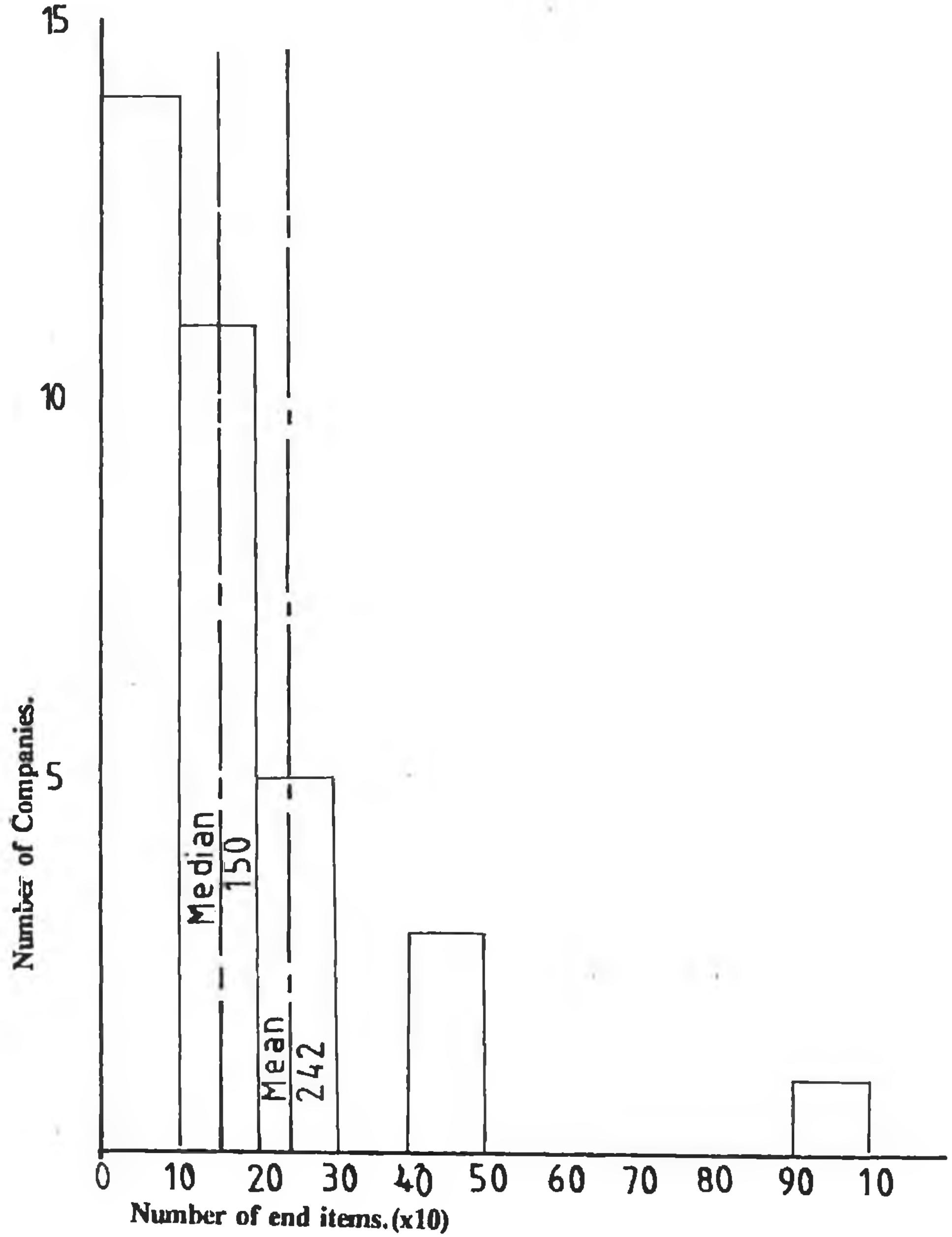
	Companies with MRP		Companies Without MRP		Total No. Companies	
	No.	%	No.	%	No.	%
Assembly	25	93	2	7	27	63
Fabrication	3	100	-	-	3	7
Both	10	77	3	23	13	30

One of the forty-four respondants failed to answer this question.

As one might expect, the percentage number of companies who engage in purely assembly operations, is nearly ten times the number engaged in pure fabrication. The number who engage in both fabrication and assembly is surprisingly high, just under half the number engaged in pure assembly. 93% of those companies, engaged in pure assembly operations operate MRP systems while 100% of the companies engaged in pure fabrication, operate MRP systems. When the two types are combined however, the percentage of the combination group operating without MRP is a large 23%, compared to only 7% of the pure assembly group.

<u>**Type of Process**</u>

In keeping with the previous questions, respondants were asked to choose which process type best describes their industry. Again the distribution of respondants over these categories is extended to include data regarding non MRP and MRP users.



Statistical Variation in End Item Data for the Group of companies Surveyed.

Fig.(4.2)

TABLE (4.5): Distribution of Companies Surveyed Over the Process Type.

	Companies With MRP		Companies Without MRP		Total No. Companies	
	No.	%	No.	%	No.	%
1 Assembly Line	18	86	3	14	21	48
2 Job Shop	8	80	2	20	10	23
3 Continuous	6	100	-	-	6	14
Combination of (1) + (2)	5	100	-	-	5	11
Combination (1) + (2) + (3)	1	100	-	-	1	2
Combination (2) + (3)	1	100	-	-	1	2

The results of this section shown in Table (4.5) again reiterates that the assembly process is the dominant force within Irish industry. Assembly manufacture worldwide is characterized by large volume production runs of highly standardized products. Labour skills are usually low, and tooling and equipment very specialized leading to an absence of flexibility on all fronts. The number of facilities engaged in a job shop type process is just less than half engaged in the previous process types. Equipment is less specialized in this environment leading to greater flexibility, and labour skills are also required at a much higher level. The number of companies involved in continuous or batch production is just under a third the number involved in assembly manufacture. 11% of the overall sample engages in both job shop and assembly-line manufacture.

Three of the five companies identified as not having MRP systems fall into the assembly line group and two into the job shop group. Note that the percentage of non-MRP companies within the job shop group is significantly higher than the percentage within the assembly line group, as might be expected, due to the nature of job shop type processes - high product differentiation.

The remaining data collected pertaining to product descriptions, and assessment, also have bearing on the performance of the material requirement planning system. This data falls into three parts, - firstly the number of end-items or products which appear regularly on the master production schedule. Secondly, the number of individual items which appear in the bill of material. Finally, the number of levels incorporated into the bill of material.

End item (product) data

Of the forty-four companies surveyed, four companies failed to provide end item figures, and of the forty replies, four of these fell outside the range of the graph. (Fig.4.2). The mean of the graph is 242, and the standard deviation is 216. The median of both graph and data is 150. The range of end items is 9 to 7000. If the four end item figures which fall outside the range of the graph are included in the mean calculation, the resultant mean is 718, almost three times the mean with these values left out. The standard deviation with these values included increases sevenfold to 1493.

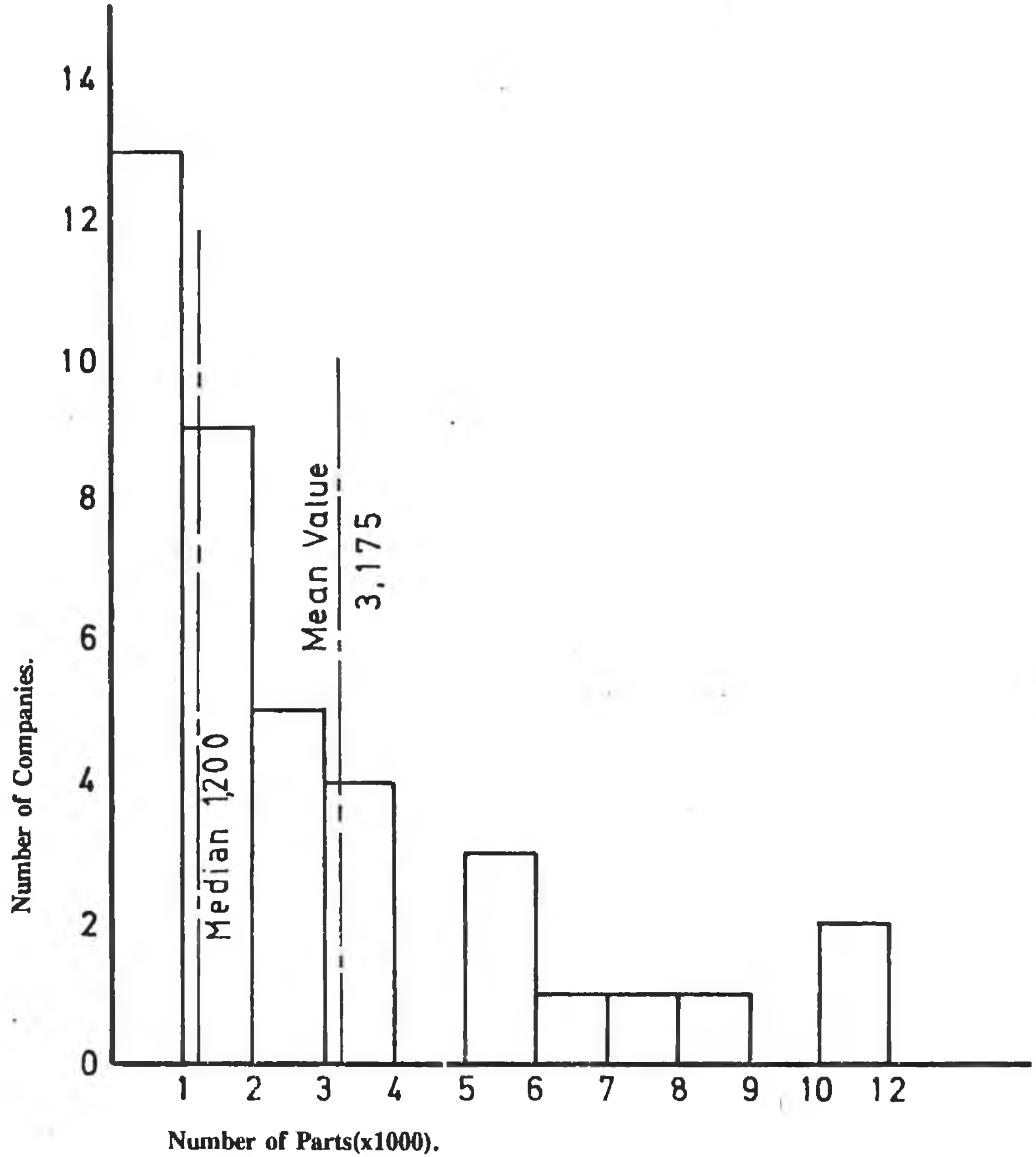
Because 90% of data (36 companies) fall within the range specified on the graph, it may be concluded that the four figures which fall outside the range specified are biasing both the mean and the standard deviation and will therefore be ingored.

Part number data

The response rate to the part number question mirrors that of the end product data, with four voids. In this case however, only three of the results obtained lies outside the range of the graph. (Fig 4.3). The mean of the graph is 2969, and when the figure outside the graph range are included it increases to 3150. The standard deviation of the graph is 2402, and rises to 3330, when all the data is included. included. The median of the complete data set is 1800 and that of the graph 1200. Because 93% of the data falls within the graph range, both the mean and standard deviation of the graph can be taken as that of the complete data set.

Bill of materials

43 of the respondants answered the question regarding the number of levels in their



Statistical Variation in Part No. Data for the Group of Companies Surveyed.

Fig.(4.3)

bill of material. (Fig 4.6). The range of values obtained varied from one to 13. The mean of the data is 4.51 and the standard deviation 2.36.

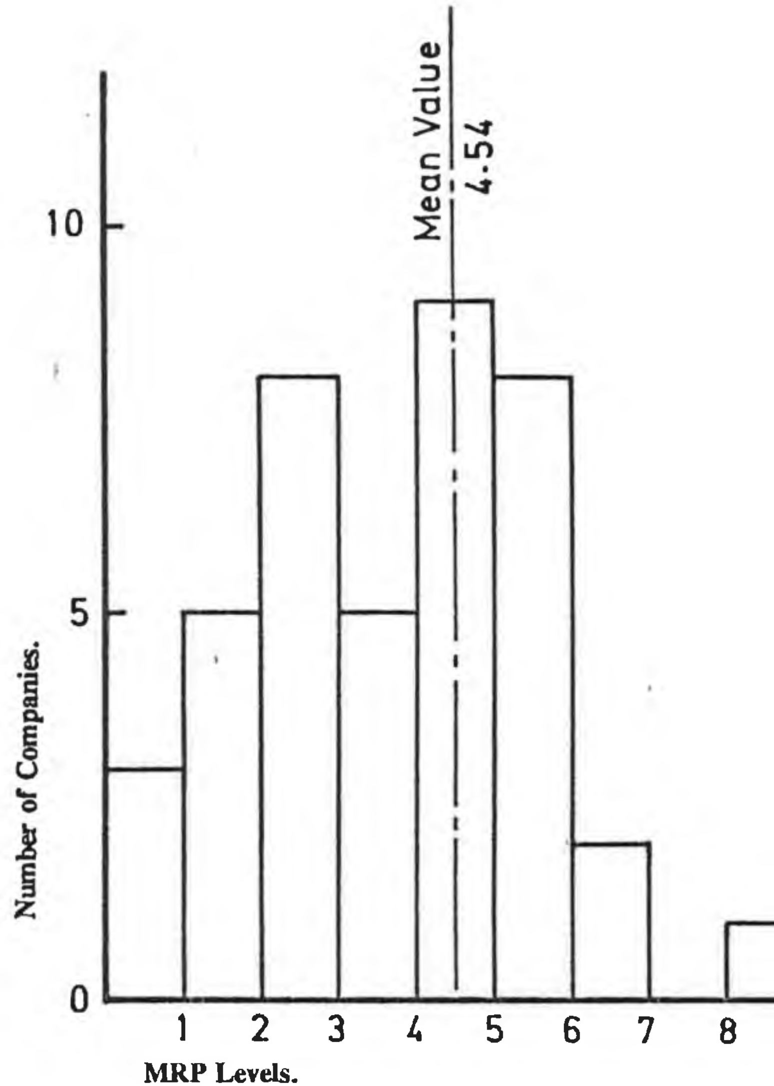
4.4.2 The state of MRP systems in Ireland

The preceding section was used to establish the background of the companies involved in the survey and emphasizes the nature and range of these companies. This section presents the results pertaining to the extent of computerization within these companies and also the degree to which information being input and processed by machines is accurate. It is not possible to assess the performance of computerization in relation to plant operation unless a certain confidence level, in terms of data accuracy is reached.

Extent of computerization

In order to evaluate the extent of computerization across a spectrum of individual tasks, respondants were asked to identify the areas in which tasks were carried out manually or with the aid of a computer. These tasks are arranged (Table 4.6) in order of decreasing percentage computerization. Percentages were awarded on the basis of a very simple system, whereby, if the task was computerized, it scored a one, and since forty-four companies responded, the maximum score for any task was forty-four. Parts explosion, for example was marked computerized on 28 of the possible forty-four surveys and assumes fourth position in the list, with a score of 63%.

From Table (4.6), it can be seen that the most prevalent computerized task is the inventory stock system. The purpose being solely to monitor inventory in\out and through the system. When material comes in to the factory it is entered into the system and when it leaves it is removed from the "live" system. A bill of material, parts explosion\purchasing and order release, are all vital elements of an MRP system and yet the extent to which computers are used to carry out these tasks vary significantly. Between 30% to 48% of companies carry out these tasks manually. Comparing these figures to those of average number of products and part numbers 242, 2969, respectively would seem to imply that some of these companies could well



Statistical Variation in MRP levels For the Group of Companies Surveyed.

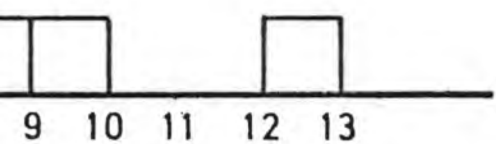


Fig.(4.6)

do with an injection of computerization.

TABLE (4.6): % Computerization of Individual Elements

MRP Element	% Computerization
Inventory stock system	81%
Bill of material	70%
Purchasing	68%
Parts explosion	63%
Order release	52%
Master production schedule	45%
Forecasting end items	38%
Shop floor control	31%
Capacity planning (rough cut)	29%
Operations scheduling	27%

Less than half the respondants operate a computerized master production schedule and less than a third, a computerized capacity planning module. A computerised master production schedule is often used interchangeable with capacity planning to perform a type of capacity planning and it is surprising to see both of these tasks at such low positions in the table. Computerised shop floor control, a vital link in closed loop MRP also takes up a very low position in the table, at 31% computerization. This would seem to imply that MRP users are using their systems for simple tasks such as order launching, ignoring some of the more advanced facilities.

Computerization vs Company Size

In order to compare the percentage overall computerization of the respondants, a weighting factor must be introduced. Respondants were asked to specify whether the individual tasks listed were carried out manually or on a computer. When a task was performed maually it scored a one. Otherwise it scored a two. The maximum score for any respondant is 20, which indicates that all tasks are computerized. Dividing the range 0-20 into five sections,

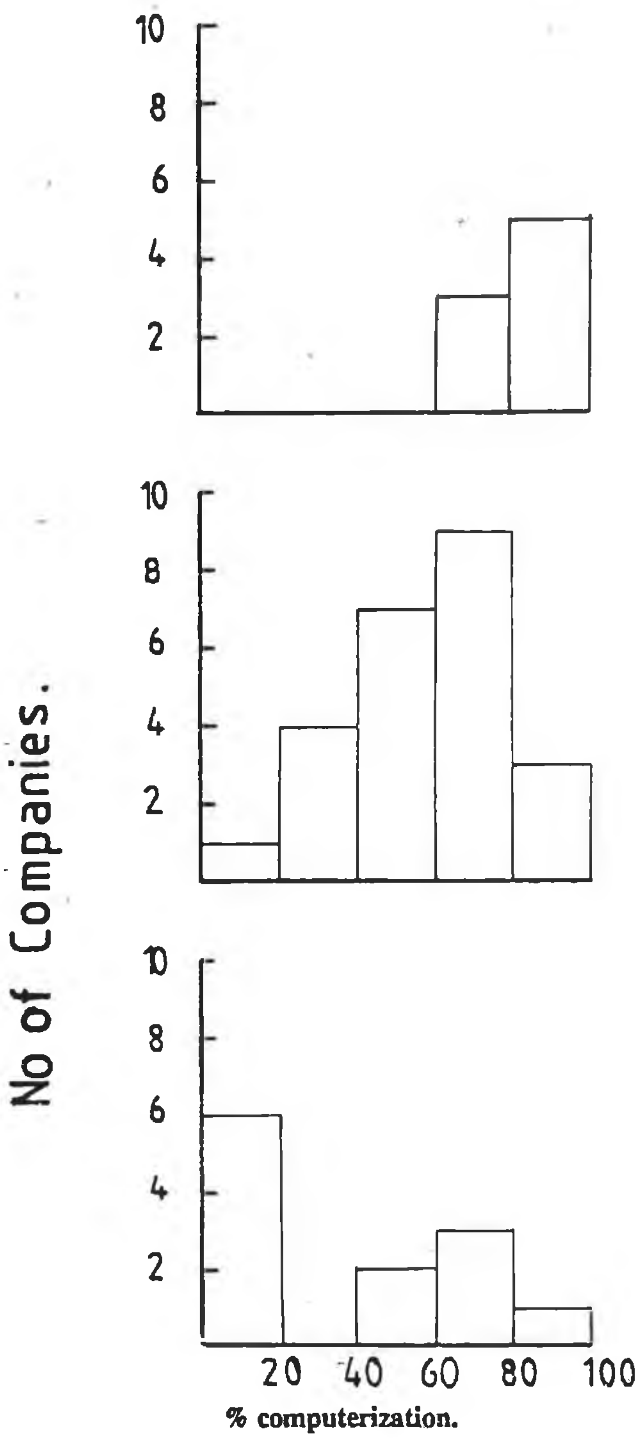
0-3, 4-7, 8-11, 12-15, 16-20.

it is possible to determine how many of the respondants fall into the 0-20% computerization bracket etc. A score of 11 for example, would imply that the respondant is in the 60-80% bracket.

TABLE (4.7): Overall Computerization Vs. Company Size.

Category	Small	Medium	Large	Total
0-20%	6	1	-	7
20-40%	-	3	1	4
40-60%	2	6	1	9
60-80%	3	8	4	15
80-100%	1	3	5	9

The above Table shows the distribution of companies within each category. As you might expect, 50% of small company respondants have less than 20% computerization. One of the small company respondants has computerized to a large extent, while the remaining five companies are in the 40-80% category. The large companies are all computerized to a very high degree, in the 60-100% category. Medium size firms are heavily concentrated in the 40-80% category (nearly 70% of all medium firm respondants are in this bracket), with 12% falling in the highest category and 20% into lower categories. The Table shows that small to medium size firms dominate the lower end of the computerization scale, and although all larger firms are concentrated at the top end of the scale, this only accounts for one third of the respondants in this category. The remaining two thirds are made up of small and medium-sized firms in a ratio of 1:3. Fig (4.5) shows the distribution of computerization for the three company sizes.



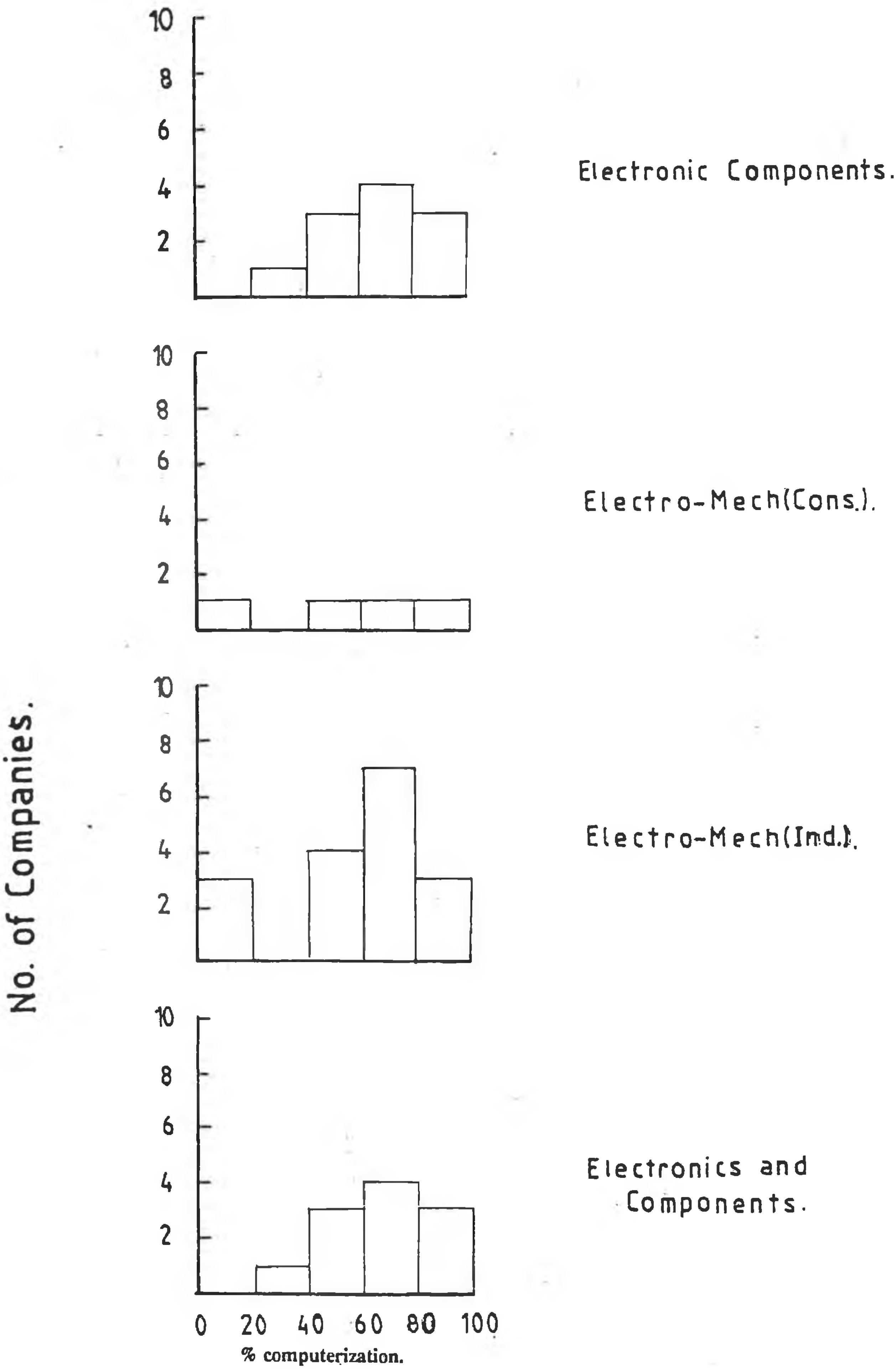
% overall Computerization Vs. No. of Companies. Fig.(4.5)

TABLE (4.8): % Overall Computerization Vs. Product Description.

Category	0-20%	20-40%	40-60%	60-80%	80-100%
Electronics/ computers	-	1	5	5	4
Electro/ mechanical, (Ind)	3	-	7	2	2
Electro/ mechanical, (Cons)	1	-	1	1	1
Electronic components	3	3	-	3	2
Total	7	4	9	16	9

The above Table (4.8) differs from the previous Table, in that the various percentage computerization categories are now distributed over the various product description categories. Electronics and computers category are fairly evenly distributed from 40-100% with one company or 9% of this group falling below 40% The second category, electro-mechanical industrial has a greater range of computerization varying from 0-100%, with nearly 50% of data falling into the 60-80% group. Electro-mechanical consumer fails to reach a peak, across the spectrum of computerization categories. Electronic components has at least one company falling into each category. 50% of this group falls below 40% computerization while 40% of data has 60% or greater computerization.

Electronics and computers and electromechanical (Ind.), dominate the 40-100% computerization categories, electronic components, the 20-40% category and both electro-mechanical (Ind.) and electronic components the less than 20% category. Fig. (4.4) describe the % computerization distribution for the various product descriptions.



% Overall Computerization Vs. Product Description. Fig.(4.4)

Accuracy of Data

Respondants were asked to comment on the degree of accuracy present in the various tasks listed below. Accuracy is very difficult to quantify, but the following system was developed to measure it approximately. The system is an extension of the previous one used to measure degree of computerization. Respondants were asked to choose one of the following adjectives to describe the accuracy of the individual tasks: poor, fair, good, and excellent. A number from one to four was assigned to each respectively. The maximum score for any task was therefore,

4x (44-number of voids)

when accumulated over all the returned questionnaires. Master production scheduling for example, with a total score of 94, and seven voids, was placed fourth highest in the list with a percentage accuracy of (94)(/4(44-7)) =63.5% The Table below summarizes the results.

TABLE (4.9): Percentage Overall Accuracy Of Data.

Description	Poor	Fair	Good	Excellent	% Overall accuracy
Bill of material	5	17	44	34	77%
Inv. records	7	14	45	33	76%
Production l.times	10	33	38	18	66%
Master production scheduling	11	38	38	14	64%
Vendor lead times	18	26	44	13	63%
Shop floor control	13	38	36	13	62%
Capacity planning	11	36	44	8	62%
Market forecasts	28	44	24	4	50%

The table shows the bill of material heading the pole for data accuracy, with inventory records data just behind. Both of these two tasks are vital to the success of MRP and as such atttempts should be made to keep updating these tasks rather than just allowing them to become static in the system. Production and vendor lead times scores, underline the problem associated with obtaining accurate lead times. In its attempt to match batch size with demand from the market, MRP, in creating a variety of production lots, ultimately varies the lead time, causing a mismatch between MRP output and actual requirements. Lead times are not independent of batch size and should not be regarded as such. Market forecasting and hence Master Production Scheduling have also scored a low degree of accuracy, with the former coming last in the list, with only 50% accuracy. Shop floor control scores a similar degree of accuracy as that calculated for other MRP tasks, such as master production scheduling etc., which raises the question as to why closed loop MRP, utilizing feedback from the shop floor is not as widespread as other MRP tasks, considering it is as accurate as some of the more prevalent MRP tasks.

TABLE (4.10): Data Accuracy Vs. Firm Size.

% Accuracy	Small	Medium	Large	Total
< 25%	-	-	-	-
25-50%	4	8	-	12
50-75%	4	15	5	24
75-100%	2	4	-	6

Table (4.10), similar to the overall computerization Table, shows the distribution of firm size, with percentage overall accuracy. The figures in the Table are arrived at in a similar fashion by assuming the top score per individual survey is 4 x 8 = 32, and then, dividing the range 0-32 into appropriate ranges. Two voids were encountered in this section. Notice that no respondants have less than 25% overall accuracy. 28% of respondants fall into the 25-50% accuracy category and over 50% into the 50-75% accuracy. Only 14% of the respondants have between 75-100% accuracy. It is interesting to note that while both small and medium size firms have wide ranging accuracies from 25-100%, large firms are wholy concentrated in the 50-75% bracket, which is also the bracket in which the number of medium-sized and small firms peak.

<u>MRP Features</u>

Respondants were also asked to answer questions regarding the special features of their respective MRP systems. The number of voids encountered in this section was surprisingly high, varying from 17 when asked about the update method, to 10 for the questions relating to pegging, cycle counting and lot sizing. Table (4.12) below summarizes the results obtained.

TABLE(4.12): MRP Features Vs. Number of Companies.

Feature		No.	%
Update method	Regenerative	13	48
	Net Change	14	52
	Pegging	19	56
	Cycle counting	22	65
	Lot sizing	17	50

Respondants were split fairly evenly between regenerative and net change update method. Of the other three features, cycle counting is the most prevalent, with 65% of respondants employing this feature. Lot sizing is the least prevalent, with only half the respondants exhibiting this much publicised feature. 21% of respondants (7 companies) employ none of these features, and the same number utilize two while 32 (11) companies use all three features. Each of these features have proved useful in the successful implementation of MRP and it is surprising to see them all in such a limited operating environment.

Table (4.13) distributes the number of features per company over firm size. It may be seen that only 12% of all small firms have all three features compared with one third of medium firms, and 43% of large firms. In fact the Table demonstrates that small firms are more likely to have no added features. 10% of medium firms also have no added features, but all large firms' respondants have at least one feature.

TABLE (4.13): Number of Features Vs. Firm Size.

No. of features	Small	Medium	Large	Total
Three	1	6	3	11
Two	1	5	3	9
One	1	5	1	7
None	5	2	-	7

MRP Usage

The final table (Table 4.14) in this section, results from the question which asks respondants to define their own interpretation of MRP. Respondants were given three choices and asked to choose one of the three. When respondants referred to MRP as "narrow", this meant that MRP referred only to parts explosion and order launching. The broad context defines closed loop MRP. The final category allowed respondants to present their own interpretation of MRP..

Six respondants failed to provide an MRP definition. Of these, five were not MRP users, and one was in the process of installing a system. 34% of respondants (15 companies) chose the broad MRP definition, and 43% (19 companies) only used MRP for requirement generation. The remaining four companies, or 9% of respondants presented their own interpretation. Three of these other definitions were that of A a Wight [ ] "A" class user, and the other, an embellished requirement planning definition.

TABLE (14): Usage of the Term MRP

MRP usage term	No. of companies	% of companies
not at all	6	14
broad	15	34
narrow	19	43
other	4	9
Total	44	100

It is interesting to see that only three companies describe themselves as "A" class users, yet nine companies fall into the 80-100% overall computerization category. Six companies therefore, who use the broad definition of MRP have a very high degree of computerization. Similarly comparing the broad definition to the 60-80% category, 15 companies fall into the broad category which must be made up of both the six companies form the 80-100% and 15 companies from the 60-80% category, which implies that six companies which supplied the narrow definition have a very high percentage computerization for that definition. The 19 companies which fall into the narrow category are scattered in the 20-80% overall computerization, with nearly twice as many companies falling into the 40-60% category. This lack of uniformity in describing the state of MRP systems underlines the need for a concise classification system.

4.4.3 MRP Benefits

This brief section chronicles the benefits in percentage terms which MRP implementation brings about. Respondants were given a list of four potential benefits, and were asked to give each one a mark from one to four. The numbers stand for *little, some, much* and *very much,* respectively. The system then used to work out percentage benefits, mirrors that of the corresponding tables in the other two sections. Table (4.15) also exhibits the percentage scored by the various categories offered.

TABLE (4.15): Percentage Benefits Derived From MRP

Benefits	little/ none	some	much	v.much	overall score %
Improved customer satisfaction	9	40	37	14	64%
Better production scheduling	3	31	46	17	69%
Improved man. lead times	15	29	47	9	63%
Better inventory control	-	17	37	46	85%

The Table is headed by better inventory control, scoring 85% out of a possible 176. Relating inventory control to inventory stock systems and bills of material, percentage computerization scores, it is obvious that the majority of respondants realize that much is to be gained by their computerization. Improved production scheduling is second in the list, with a score of nearly 70%. It would appear however from percentage computerization figures that this task is the least likely to be computerized appearing last on the list.

Improved customer satisfaction and improved manufacturing lead times, score approximately the same in the benefit Table. Considering only 43% of respondants operated either closed loop control MRP systems, or a more sophisticated form of MRP, it may be assumed that quite a high percentage of respondants are finding improved customer relations from implementing more rudimentary MRP. Relating improved production lead times to the measure of accuracy afforded to the latter, it is interesting to see that both score approximately the same - 66% accuracy, 63% improvement in lead times. Of course the former relates more to the accuracy of the lead times held within the system, and the second to actual practical production lead times. The difference between the two scores might be expected to be wider, due to the cumulative effects of inaccurate lead times at each station.

TABLE (4.16): Benefit Overall From MRP System

Category	Small	Medium	Large	Total
0-25%	-	-	-	-
25-50%	2	1		3
50-75%	4	10	1	15
75-100%	2	12	2	15

The Table 4.16 distributes overall benefits over the various firm size category. The vast majority of companies stated an overall benefit of over 50%. Only 3 companies fell below the 50% mark.

Both small and medium firms were spread over the 25-100% range, which compares to the accuracy ranges, also encountered in this firms. The range of percentage benefits encountered in large firms is wider than that of overall accuracy, being concentrated in the 50-75% range in the latter, and 50-100% in the former. Accuracy may therefore be related to benefit. Each firm size however peaks at a slightly higher percentage benefit than it does in the accuracy Table.

4.4.4 Implementation Problems

Much has been written about the ideal method of approach, when initiating the changeover from manual to the computerized manufacturing control system. Many companies operate both systems simultaneously, for a time, so that a certain level of confidence can be achieved in the computerized system before rejecting the old manual system.

A list of commonly recurring problem areas has been compiled from literature. Respondants were then asked to comment on the degree to which the area had caused problems. Four choices were offered, *little or none, some, much, very much,* corresponding to one to four respectively. A similar marking scheme to the one previously used was employed to produce the following Table. (Table 4.17).
The percentage number of companies falling under each heading are also listed.

TABLE (4.17): Individual Implementation Problems Vs. % Magnitude of Problem

Problem Type	Little	Some	Much	Very much	% overall degree to which it caused problems
Master production schedule	24	33	24	18	61%
Lack of suitable s/ware	23	45	26	6	54%
Production lead times	26	57	17	-	48
Lack of expertise	31	35	23	11	48
Constraint of h/ware	53	19	19	9	46
Cost of s/ware	50	26	12	12	46

The problems, were basically of two types: - those relating to MRP tasks - master production schedule and production lead times, and those relating to the MRP operation and installation.

Master production scheduling heads the list, scoring 61%, justifying its place in the list, It is interesting that production lead times proved to cause significantly less of a problem than master production scheduling, scoring just under 50%.

Unsuitable software caused the greatest problems in relation to MRP operation and installation, followed by lack of expertise, within the company. The relationship between both of these problems is interesting. If experts in the field of MRP were employed within the company, this might possibly eliminate the purchase of unsuitable software. It would also avoid the purchase of unnecessary hardware, when the system requirements exceeds that of present hardware restrictions. The cost of buying software scores the lowest in the list, however this would be exacerbated with the purchase of unnecessary software.

Respondants were also asked to provide information on any other major problems encountered during MRP implementation. The replies were many and varied, loosely falling into three subsection. Table (4.18) lists the replies.

TABLE (4.18): Major Problems Encountered During MRP Implementation.

Software:	**Does not have multi-currency capability.**
	Lack of available software for fabrication.
	Inability to integrate with other systems.
	Only have regenerative MRP
People resource:	**No MRP champion.**
	Reluctance of staff to change.
	Lack of expertise in raw material planning and MRP
	Lack of skilled personnel.
	Lack of understanding of need for discipline and formal proceedings.
	Lack of management committment.
	Ability to manage change and training requirements.
	Lack of company-wide acceptance.
	Problem with convincing parent company of requirements.
Data accuracy:	**Transferring data from old to new system.**
	Poor initial documentation.
	Poor data integrity.
	Poor sales forecasts.
	Bill of material structure not conducive to system.
	Lack of integrity between stockroom and shop floor.

The replies relating to software reiterate the need for deciding upon the exact requirements of the company system before making the choice to purchase\develop software.

In order to complete a successful changeover to computerization, the total committment of all the people involved is required, under the guidance of an "MRP champion". All replies relating to the people resource underline this need.

The need for accuracy, when implementing MRP is qualified by the adage "rubbish in, rubbish out", in relation to data. The inability to keep track of stock, once issued to the factory floor, prevents any sort of backflushing procedure, to stock count and the formal discipline of the MRP system breaks down. This and other data accuracy-related problems must first be solved before attempting to computerize the data.

Once the decision to implement MRP has been made, a decision must then be made to decide on the approach which must be adopted in order to bring about the eventual success of the excercise. Various options are open to the perspective MRP implementer, including software vendors, computer manuals, consultants, or books and periodicals. Table (4.19) lists these options in the order of decreasing % utilization,

with the percentages scored within each category also listed.

TABLE (4.19): Implementation Approaches

Implementation approach	Little/ None	Some	Much	V. Much	% Utilization overall
Software vendor	47	13	28	13	49%
Books/periodicals	42	42	12	3	45%
Consultants	55	30	9	6	40%
Computer manuals	74	20	6	-	33%

If there is to be an MRP champion within the firm, then some time must be spent by an individual reading and understanding articles and books. The table shows that greater emphasis is placed on consulting software vendors (who are not experts in the manufacturing area) than on reading. Consultants are also used, although the degree to which they are used, may be dictated to by the cost involved, which may prove to be quite high. Manuals are consulted least, presumably relying on the vendor to explain the inner workings and features of the packages on offer.

TABLE (4.20): Software Source

Source	% Utilization
Vendor supplied with modification	55%
Vendor supplied without modification	24%
Develop internally	12%
Both	9%

Table (4.20) above, lists the various sources of software available and the corresponding percentage, indicating the degree to which the respective sources were utilized. The majority of companies approached vendors, - 79% of the sample -, 70% of which required a degree of customization. Only a very small percentage developed their own system - 12% of the sample, which is consistent with the very small number of companies who had an MRP expert or "champion" among their personnel. Only 9% of companies jointly used their expertise on their own manufacturing control system, and the vendors expertise on the packages available, and customization required.

4.4.5 JIT Implementation

MRP originated and developed in America, and slowly filtered through to Europe and the rest of the world. In a similar fashion, Just-In-Time manufacturing techniques originated in Japan, and are slowly becoming known in the rest of the world. Just as it took time for companies to initially realise the benefits of computerization and begin implementation, manufacturers are wary of JIT techniques and resistant to try to implement them.

From Table (4.21) it is possible to compare the number of companies who are aware of JIT and its various elements, and those which have actually tried to implement some of those elements. Of the 70% of respondants who had prior knowledge of JIT, 27 of these companies had begun implementation. One third of these 27 companies hoped to further implement JIT in the future, while the remaining two thirds had decided to curtail their JIT activities. Just over half the companies which had not as yet embarked on a JIT program intended to in the future, while the remaining 7 companies, had no intention to at present.

TABLE (4.21): JIT Implementation Statistics

Comment	No. of companies	% of total sample
- JIT techniques may be successfully implemented in their environment.	30	70%
- have implemented some JIT techniques.	27	63%
- intend to implement further techniques in the future.	9	21%
- do not intend to implement further techniques.	18	42%
- have not implemented any JIT techniques but intend to in the future.	7	16%
- do not intend to implement any techniques.	9	21%

Table (4.22) demonstrates the number of companies who have or intend to embark on a JIT program distributed over firm size. Of the 27 firms which have a JIT program, the majority of firms (17 are medium-sized), while the remaining 10 firms are split evenly between large and small firms. 4 medium-sized firms intend to embark on a JIT program in the future, ensuring that all or 100% of the medium firms have or will have JIT programs. Only 7 of the 12 small firms have, or will have JIT programs, and a surprisingly low 50% of large firms have or intend to have a program.

TABLE (4.22): JIT Implementation Vs. Company Size

Comment	small	medium	large	total
- have already implemented some JIT techniques.	5	17	5	27
- have not already implemented JIT but intend to in the future.	2	4	1	7

As mentioned previously JIT is a manufacturing philosophy, which encompasses the complete manufacturing procedure. As such, JIT has many facets, all the techniques all of which are listed in Table (4.23). They deal with tasks as varied as quality - zero defects - to employee training, through to developing uniform work loads, on the manufacturing lines.

When companies first decide to implement some JIT techniques, their interpretation of the techniques with which to start may not coincide. This point is demonstrated in Table (4.23), which shows the percentage of the total sample, who intend or have already implemented the various techniques. This varies from 47% to 12% implementation at present. It is interesting to see that the JIT delivery technique leads the Table, bearing in mind that we are an island nation. Cross training of employees is second in the list, with 40% of companies already operating a scheme and another 19% planning to in the future. Controlling material flow through the use of signals (card etc.) instead of relying purely on the requirement planning output is also implemented to a high degree, with 38% of companies using Kanban techniques. One of the more popular terms in Irish manufacturing circles today is ISO 9000, and quality standards which accounts for 37% of the sample pursuing the zero defects goal. The ultimate goal of any company trying to achieve manufacturing excellence through JIT is the ability to produce unit batches efficiently. This cannot be achieved, unless set-up times per job are reduced or eliminated. With this in mind, it's interesting to see that the percentage of companies trying to reduce set-ups, is 10% lower than that number who are aiming for JIT delivery.

TABLE (4.23): Implementation Techniques Vs. % Implementation

Technique	% implementation at present	% implementation in the future
JIT delivery	47%	26%
Cross training	40%	19%
Kanban	38%	12%
Zero defects	37%	30%
Reduced set-ups	37%	28%
Group technology	23%	16%
Total preventative maintenance	19%	12%
Uniform w\loads	12%	23%

The first five techniques differ by only 10% however the first and sixth techniques, differ by twice that, as group technology - a method of organising the factory layout by product rather than process, is practised by only 23% of respondants. The number of companies who practise total preventative maintenance is even lower, with only 19% of respondants having TPM programs.

The ability to operate with uniform work-loads will always be difficult to achieve, because companies cannot accurately ascertain the magnitude or quantity of orders. As more companies begin to rationalise their supplier base, and place their trust in one supplier, the number of companies operating with uniform work loads may increase above 12%.

Table (4.21) shows that almost 27 of the 44 respondants have already had some JIT experience. Table (4.23) lists the various techniques involved in JIT manufacture. For a company to claim prior JIT experience therefore, it is only necessary to have implemented one of more of the techniques. From Table (4.24) it can be seen that the majority of respondants (63%) have tried to implement 50% or less of the techniques. One of the small company respondants possessing a very progressive outlook, has implemented seven of the eight techniques. The remaining small companies however are concentrated at the bottom of the Table. The five large firms professing JIT experience are evenly distributed between seven and three techniques, with the remaining large firm having only tried one technique. Only 35% of medium-sized firms have implemented five of more techniques.

TABLE (4.24): Implementation of Techniques Vs. Company Size

No. of implementation techniques	Small	Medium	Large	Total
Eight techniques	-	1	-	1
Seven techniques	1	2	1	4
Six techniques	-	1	1	2
Five techniques	-	2	1	3
Four techniques	-	3	1	4
Three techniques	1	4	-	5
Two techniques	2	2	-	4
One technique	1	2	1	1
Total	5	17	5	27

As mentioned previously, the Irish electronics industry consists of approximately 250 firms. The forty replies obtained make up a significant proportion of the whole industry and as such may be taken as fairly representative of the industry as a whole.

4.5 DISCUSSION

4.5.1 Company Description

The results show that the range of industries in terms of size, goods manufactured, manufacturing policies and processes is very wide although in many cases disproportionate. By our definition, the majority of firms operating within Ireland are medium-sized, (48%), with the remaining firms being equally divided between large and small firms. (25,27%).

The survey suggests that the electronics and computer industry is the larges sector in Irish industry (34%) closely followed by the electromechanical (industrial) sector, (32%). The number of firms engaged in component manufacture is also high, (25%).

The smallest section of Irish industry is that of electromechanical consumer (9%). Looking at the spectrum of the Irish electronics industry, the majority of firms are engaged in assembly operations alone, and only a very small percentage engaged solely in fabrication.

This reflects the generally held view that most industry attracted to Ireland is engaged in production processes which do not require workers with high levels of skills. What they do require however, is excellent inventory management systems and techniques in order to process and keep track of the quantities of material required for assembly. This need is enforced by the widespread use of make-to-order policies.

The need for these systems is further reiterated by the statistics obtained in relation to component and product data.

In comparison to a survey carried out in the U.S. by Crawford et al [39], the component and product data obtained in this survey appear relatively small. The reason for this may be explained by considering

a) the high proportion of solely assembly operations in Ireland

b) the standard deviation figures for both sets of data.

In the case of end item data, the ratio of Crawford's [39] standard deviation figure to ours in 35, (7637:216) and the ratio of the respective median values is 1.3 (200:150), implying that the data in the former survey is spread over a very large range, but is concentrated in a similar range to ours.

A similar situation occurs when considering part number data. The ratio of the standard deviations is 10 (24,046:2402), however the median ratio is slightly higher at 7.5 (9000:1200).

The bill of material figures are much more comparable, with the range of the U.S. survey being only twice that of the Irish survey. The ratio of the means is 1.4 (6.43:4.51) and that of the standard deviation, 2 (4.81:2.36).

4.5.2 MRP Systems

Within western manufacturing circles, committment to improved inventory control is primarily guaged by the degree of computerization. Material requirement planning aside, the majority of firms have computerized some inventory control aspects. The overall committment to computerization within the Irish survey is not quite as high as that exhibited in another survey carried out by Andersen et al. [39]. Both surveys demonstrate varied committment to individual elements, and while priority is concentrated in similar areas, individual committment to the elements is higher in most cases in the American survey, - order release, purchasing and forecasting being the notable exceptions.

The distribution of overall computerization, would appear to be dictated to by both company size and product description. The lower end of the computerization scale is dominated by small firms, and electronic component manufacture. The top end of the scale is dominated by large sized firms and both electronic and computer manufacture, and the electro-mechanical (industrial) sector. Medium-sized firms demonstrate and average committment to computerization and the consumer section of the electromechanical sector shows no obvious committment to any level of computerization.

Trends in the accuracy data obtained in the Irish survey mirrors that found in the US [39]. The three inputs to material requirement planning (-M.P.S., I.R., B.O.M.-) are considered to be the most accurate of all MRP elements, with shop floor control and capacity planning proving difficult to control on both sides of the Atlantic. It is interesting to see however, that in America, vendor lead times are generally more reliable than production lead times whereas in Ireland the reverse is true. This may account for the high degree of computerization exhibited within the purchasing element in Ireland, as compared to that of America (Ireland 25% > USA). Accuracy of data would appear to be fairly independent of firm size, with each firm size category peaking in a similar range. (50-75% accuracy) Overall accuracy figures for Irish industry are lower than those of the USA.

On commenting on survey results so far, I have refrained where possible, from using the term MRP. This is because the survey demonstrates the wide variey of definitions industry used to describe requirement planning processes. A surprisingly high number of firms (7%), classify themselves as being a Wight [40] "A class user", the number being similar to that found in the survey of Andersen et al [39] in 1981. Comparisons may also be made between the number of firms which fall into the broad and narrow categories. The Irish survey however also presents figures pertaining to non-MRP users, with the percentage of companies not using MRP, being nearly twice the number of "A class users".

A comparison between overall percentage computerization and MRP usage highlights the varying definitions of what exactly MRP entails. Two important conclusion can be made, concerning MRP usage. Firstly the variety and types of MRP systems currently in use is necessarily as wide as that of the number of MRP users. Secondly, the distribution of MRP users today within loosely defined categories is comparable to that found in the USA in 1981, ten years after the MRP "push" began.

The final part of this section discusses the use of some of the more prevalent MRP features used to enhance results. The first of these concerns the method of updating files and generating requirements. The number of firms employing regenerative MRP in Ireland at the present time is much lower than that found in the USA in 1981. The number of companies employing net change systems is however much higher.

Net change systems would usually require greater degrees of both accuracy and operating discipline, if system nervousness effects are not to impact upon requirement results. Taking into account the lower accuracy figures obtained in the Irish survey, and also the large number of voids obtained in answer to this question, certain doubts may be raised as to the widespread understanding of MRP operating principles.

The number of both Irish and American companies employing both cycle counting and pegging are comparable, however a slightly larger deviation in the respective percentage users occurs within the lot sizing function, with Irish firms being more likely to use a lot sizing procedure than their American counterparts. Analyzing the relationship between firm size and added features, it appears that the latter are very much dependant upon size, which again may be accounted for by the lack of any formal filtering procedure the encourage the spread of information.

4.5.3 MRP Benefits

The survey shows that of all the benefits listed, the greatest benefit perceived by the majority of respondants is that of improved inventory control, with improved customer satisfaction nearer the bottom of the list. This result, together with evidence from previous sections, would suggest that within the majority of Irish firms, MRP and its associated functions (leading to MRPII) have tended to stagnate within the bounds of inventory control, due to a myopic perception of MRP, solely as an inventory control tool, rather than the driving force behind the manufacturing system as a whole.

An assessment of overall benefit, leading to inproved performance from the implementation of material requirement planning leads to the conclusion that yet again small firms achieve lower rates of performance improvement than either medium of large firms . Again this may be attributed to a lack of support availability and educational programs for small firms.

4.5.4 Implementation problems

The process of MRP implementation is of key importance to both getting the system operational, in as short a time span, with little cost as possible, and in squeezing maximum benefit from the system.

When companies were asked to present their own recurring problems in implementing MRP, the problems fell into three distinct categories, the majority of which would have remained present and undetected within the system, if it were not for the implementation project. Problems with data accuracy, people management, exist independently of MRP, the latter serves only to uncover them.

It must be said therefore that in order to improve inventory control practices - a major MRP benefit - company-wide procedures must be questioned and improved. The actual methods of approach to the implementation may be taken as indicative of the level of understanding and awareness to be found within the ranks of the propective MRP user. Irish firms tend to rely more heavily on the expertise of "outsiders" rather than relying on their own initiative and knowledge. The Andersen et al. [39] survey concluded that U.S. firms were less likely to rely so heavily on outsiders, preferring to consult books and periodicals.

The Andersen survey also presents an interesting finding which is very applicable to the state of Irish manufacturing today. It states that the eventual class of MRP user was found to be dependant upon both the implementation approach and also problems encountered. Companies which tend to develop their initial systems - concentrating solely on basic requirements generation into a broader operational base., encompassing the many functions of closed loop MRP tend to be those companies in which top management play and active role in improvement processes, and have helped to initiate and encourage a formal procedure to implement MRP

4.5.5 JIT Implementation

As discussed previously, within the realms of western manufacturing, particularly in Europe, the Just-In-Time manufacturing philosophy is a relatively new concept. It is surprising therefore to see such a high degree of interest in JIT among Irish firms, This interest compares favourably with that described by Voss et al. [40], discussing a survey carried out among British manufacturers. Not only is the level of interest much higher in Ireland, but so too is the percentage of companies who have already initiated a JIT program. The number of Irish firms at present involved in JIT is almost four times the actual number involved in JIT in the UK.

A slightly negative side to Irish industry's foray into JIT is that relating to firm size, with the percentage occurrence of JIT in the medium-sized firm category being twice that of JIT in the small-sized category. Those small firms who have already initiated a JIT program, have only tried to implement one or two of the techniques. Medium or large firms are much more likely to have implemented at least half of the listed techniques leading to the conclusion that the extent of JIT practice is very much dependent upon firm size.

Based upon a survey of industry in Hong Kong, Cheng [41] concludes that a significant proportion of respondants regard JIT as a tool solely for inventory reduction. Irish firms implementing JIT have already demonstrated a greater committment to the JIT delivery technique than any of the other techniques, possibly due to the incorrect belief that its application in isolation will lead to a reduction in inventory. In reality of course JIT delivery is meaningless without the necessary processing capabilities developed through the use of other complimentary JIT techniques, such as reduction of set-ups, etc. It is evident however that slightly less emphasis has been placed on these techniques. The English survey of Neil et al.[42], sees British industry giving greater importance to cross training of employees.

Again the development of uniform workloads, one of the least well publicised JIT techniques, would seem to be one of the least likely techniques to be implemented in either Ireland or Britain. Again the reasons for this can be linked to education and learning opportunities available. When these tools aren't available, companies hone in on one of the more widely publicised techniques, unaware of other necessary complementary techniques.

The survey demonstrated a marked tendency among Irish firms to concentrate on those JIT elements which circumvent actual JIT practice on the factory floor. Total preventative maintenance (TPM), group technology (GT), and set-up reduction techniques which do not cause significant disruption to existing working practice. A similar conclusion may be made regarding the survey of Neil et al. [42].

4.6 CONCLUSIONS

Irish industry is still predominantly centred around push methods of production control (see Chapter 3). The majority of industries utilize material requirement planning (MRP) systems to both drive and control production. Despite this concentration of effort within the confines of MRP, MRP has failed - to a great extent - to permeate all levels of the manufacturing hierarchy. The chronicled development of MRP systems expansion to the realms of manufacturing resource planning (MRPII), so typical of America in particular, has failed to reach any significant proportions within Irish industry in general, tending rather to stagnate within the limits of requirements generation.

Although Irish industry as a whole has fallen victim to this apparent inertia, it is the small sector which is affected the most. Here, misconceptions are compounded by lack of formal training and resources. The survey results have demonstrated that small firms are less likely to develop good manufacturing control systems than either of the other two sectors. Only 2% of survey respondants were Irish owned companies, (Landy's survey 1984, [43] found only 40 Irish owned companies in all Irish industry), which is fairly indicative of the "real" extent of Irish industry. Both of these firms fell into the small firm sector, as would much of indigenous industry, initially at least.

In today's ever changing markets, the possibility of gaining competitive advantage may be improved by updating methods of internal control. If indigeneous firms are set-up and are not afforded any insight into the tools of control and methods of improvement, they will not be able to attain or retain competitiveness.

Within Irish industry as a whole, the level of awareness of Just-In-Time techniques is surprisingly high. The survey has shown however that rather than being interpreted as a manufacturing philosophy, industry has tended to concentrate on those techniques which have direct Just-In-Time connections, such as JIT delivery, and have taken little heed of other techniques. Any methods whose implementation might disrupt the flow of production, such as Group Technology (GT), have been avoided.

As with MRP, JIT implementation is very much dependent on firm size. Small firms being less likely to implement JIT than large\medium firms. This raises severe problems when small firms vying for business from large firms, are asked if they can perform to Just-In-Time requirements. If the proper tools are not in play, this may prove difficult.

Although the IDA continues to attract multinational to our shores, no long term solutions have developed from their policies. Industry in Ireland is still predominantly of the assembly type, and is generally foreign owned. These firms have done little to aid the growth of indigeneous industry. If any significant advanced in the development of indigeneous industry are to be made in the future, it must be accepted that, in order to meet the demands placed upon them by today's manufacturing markets, manufacturers must also be given on-going access to information and advice relating to improvements, advances in manufacturing control principles and practices.

CHAPTER 5

MATERIAL REQUIREMENT PLANNING

5.1 INTRODUCTION

As outlined in Chaper (2), material requirement planning is a method of inventory control, which developed from the inadequacies of the old order point systems, namely their inability to take account of both lumpy and dependant demand. Although the principles behind MRP had been practised as far back as the 1940's, its' computerisation in the 1960's, and the "MRP Crusade" of the American production and inventory control society, really brought MRP to the fore.

Initially MRP performed only requirement planning, producing both production and procurement orders. This was later extended to include such features as capacity requirements planning, rough cut capacity planning etc. The combination of these features, along with the ability to feedback information from the execution to the planning stage, was termed "Closed Loop MRP". Manufacturing resource planning (MRP II) was later coined to describe the integration of closed loop MRP with business and financial planning modules.

MRP is a computer based tool which in its most basic form, is used to generate material requirements, at the various stages that constitute the production process. Requirements are generated in discrete time periods, termed time buckets or planning periods, within a certain planning window - the planning horizon. The span of the planning horizon, is equal to the sum of the time periods times the length of the time period. (Varys from 1 day to 1 week).

MRP inherently differentiates between items which must be bought in and those which must be produced. The function of the system is to ensure that:

"The requirements of both bought in and manufactured items are adequately covered by purchase and shop orders respectively".

MRP achieves its aims through the use of a concept called time phasing. This necessitates that:

1. Products are defined in a hierarchial form referred to as product structure or bill of material.
2. Production lead times for each and every item within the product structure also be maintained.

The program then requires gross demand figures (again specified to within a discrete time period) to drive the system and compute requirements.

5.2 SYSTEM TYPES

There are two basic alternatives of MRP system implementation.

1. Net change systems.
2. Schedule regeneration systems.

The final output from both system types are the same but differences do arise in:

1. The treatment of inventory status.
2. Frequency of replanning.
3. Invitation of the planning process.

The greater the frequency of replanning the more up to date, the data in the system will be, however, requirement planning may take a long time, owing to the magnitude of data to be processed. Schedule regeneration offers very high processing efficiency, which limits the frequency of replanning whereas net change systems offer high replanning frequency but at the expense of overall data processing efficiency.

TABLE (5.1): CHARACTERISTICS OF MRP SYSTEMS.

	REGENERATIVE	NET CHANGE
<u>Master Production Schedule M.P.S.</u>		
Viewed as Input to MRP	Consecutive Issues Entire Contents	Continuum ,Net Differences
Explosion	Full, Periodic	Partial, Continuous
<u>Requirements Data</u>		
Logically Integration To Item Records	No	Yes
Up to Date Maintenance	No	Yes
Method of Generation	Reconstituted	Modified, Updated
<u>Item, Inventory Status</u>		
File Update	Limited to Inventory Data	Includes Required Data
Status in Narrow Sense	Maintained Continuously	Not separately maintained
Status in Broad Sense	Reestablished periodicaly	Maintained Continously
<u>Interlevel Equilibruim</u>		
Established	Only at Explosion Time	Maintained Continuously
Effect of Transaction	Only update record directly effected	Transaction triggered Explosions
Logical requirements for Allocation	No	Yes

5.2.1 Schedule Regeneration

The Master Production Schedule (MPS) triggers the requirement planning process, and each and every item must be exploded. This necessitates that every active bill of material must be retrieved during planning.

The operation of a regenerative system, falls into two distinct phases.

1. Requirements Planning (Explosion).
2. Normal Part Cycle File Updating. (Reporting\Posting Inventory Transactions).

The requirements data, once generated (in report form) is not maintained within the system. This then creates the problem of trying to maintain integrity between the requirements plan, and actual production. Regenerative systems, are typically found, in smaller companies, who are relatively new to the MRP environment, and whose software has been purchased rather than developed in house. (See Chapter 4).

5.2.2 Net Change Systems

If the Master Production Schedule, which drives regenerative MRP systems, were to be considered a moving picture of requirements over a period of time, net change systems would be considered to be 'Snapshot' driven, - only a small part of the MPS is subject to explosion at any one time. This type of system is usually referred to as being transaction triggered.

Requirements data, once generated is maintained by the system and the system can therefore be updated at any one time just by adding or subtracting net differences. Because requirements data is maintained within the system, maintaining data integrity both within records themselves, and between parents and components, is very important. The former is referred to as record balance, and occurs when projected on hand balances, correspond to existing gross requirements and scheduled receipts. The second is referred to as inter-level equilibrium, and is achieved when gross requirements of component items correspond exactly in both quantity and timing to parent items' planned order releases.

In net change systems, no difference arises between planning and updating. There is however a logical requirement for allocating on hand quantities when parent planned orders become schedule receipts. Some of the more negative aspects of net change, include:

1. Reduced 'Self Purging' capability, - due to fact that requirements are held in the system.
2. Nervousness of a net change system.

Net change systems are more typical of large companies, who have a history of MRP implementation. Often the system is on-line to react instantaneously to unplanned changes as they occur.

5.3 PROCESSING LOGIC

The objectives of any MRP system, is to determine:

1. When to order
2. How much to order.

This it does by computing net requirements, and time phasing results so that each and every component is covered by either a shop order or a purchase order. Orlicky [32], defines a general rule for MRP processing logic.

> "Mutual parent/component relationship of items, on contiguous product levels, dictates that the net requirements on parent level be computed, before gross requirements on component level can be correctly determined".

In order to understand the processing logic behind MRP implementaion, the following definitions need to be stated.

1. Gross Requirements: Total demand for an item within any given time period (GR).
2. Schedule Receipts: Total receipts in any given planning period (SR).
3. On Hand (Expected Inventory): This may be defined at the beginning or end of a planning period. It signifies the level of inventory left, at the end of the requirements planning run (OH).

4. Planning Period: Unit of time, utilized by Master Production Schedule, the planning horizon, usually expressed in terms of the next N. planning periods (t).
5. Lead Time: Time required to assemble an item or sub-assembly or, wait on a purchased part (Expressed as multiples of the planning period). (L).
6. Net Requirements: Planned order releases, which must be made owing to inaccurate coverage (NR).

In its basic form the MRP equation may be expressed as:

$$OH + SR - GR = OH \qquad \text{Eqn. (5.1)}$$

Equation (5.1) means nothing however, unless the equation is modified to deal with both product structures (j) - the idea of parent items -, land lead times - time phasing (t).

$$OH_{t,j} = OH_{t-1,j} + SR_{t,j} - GR_{t,j} \qquad \text{Eqn. (5.2)}$$

$$NR_{t,j} = (-1)\,\mathrm{Min}\,\{\,0,\ OH_{t+L(j),j}\} - \sum_{M=1}^{t-1} NR_{M,j}. \qquad \text{Eqn. (5.3)}$$

Equation (5.3) arises, because net requirements, only occur when the on hand quantity computed in Equation (5.2) becomes negative. The incorporation of lead times require that, for any item, to be available in period t it is required in time period t - L. The on hand amounts computed in equation (5.2) are cumulative, and so to calculate, on hand amounts for a specific period the sum of all net requirements occuring in previous periods must be subtracted from the period in question.

$$GR_{t,j} = (SR_{t+L(k),k} + NR_{t,k})\, q_{jk} \qquad \text{Eqn. (5.4)}$$

Gross requirements of item j, are equal to some multiple (q_{jk} quantity of component j, required per parent k) times the scheduled receipts of k, plus any extra net requirements. The schedule receipts term, must be offset, by the lead time, by virtue of time phasing however, the net requirements has already been offset, in eqn. (5.3).

5.4 MRP AND PRIORITY PLANNING

In order for an MRP system to produce valid requirements, it must have the ability to keep open order due dates (schedule/receipts) up to date, and valid. The function of the system, may therefore be defined locally as being:

"To ensure that the due date, and date of need coincide."

Initially, when planned orders released, become current, these two dates coincide. In real manufacturing systems however, a distinction arises between order priority as defined within MRP and operation priority, as defined on the shop floor. Limited capacity, at various resources, shop scheduling, dispatching etc. all effect operation priorities, and hence cause a gulf to develop between the two dates. Orlicky [32] likens an MRP system to a Push and Pull System rolled into one, whereby the push or order launching aspect of MRP is supported by an 'Expedite' mode which is pulled into action, to re-establish priorities.

The backbone of MRP, is obviously its ability to deal with dependant demand. In order to discuss priority dependance, a distinction must be made between real and formal priority. Real priority may be said to occur at the actual date of need, whereas formal priority corresponds to initial priority assigned.

Priority dependance, recognises that the real priority of any item, depends upon the availability, of some other item within the product structure. If for example, product A, (Fig. (5.1)) is due to run out in week 12, and B is scheduled for completion in week 11, but suddenly, sales drop and have surplus of A items, then the real priority of B, is a lot less than the formal priority. (Vertical Dependance). Similarly if item, B, is unavailable for some reason, then the, priority of C, is lowered by virture of it being a component in the same sub assembly. (Horizontal Dependance).

5.5 OPERATING VARIABLES

5.5.1 Lot Sizing Rules

Depending on the lot sizing method chosen, each, replanning causes a certain amount of nervousness in the system. The replanned order, must again be exploded through the product structure, affecting both quantity and timing. Ho [44] suggests that the more dynamic the lot size, the more it impacts on system nervousness and therefore, a fixed order quantity. Lot sizing rule should be used for higher level items and the dynamic rules for lower level items.

5.5.2 Length of Lead Time

It is a question of great debate, as to the manner in which lead times should be held static in the system. In reality lead times are dependant upon lot size and inventory in the system, and hence should be dynamic.

Lead times in MRP systems, should be held in their shortest form, which means that when the actual lead time is longer than expected, a change occurs in the open order (scheduled receipt), and this must be replanned. A similar situation arises when the lead time is longer than actually required to complete the job. Orlicky [32] refers to planned and actual lead time, where the former is the lead time value static in the system used for planning order releases, and the latter, reflects a revised due date, brought on, by replanning. This actual lead time, therefore, is a function of the relative priority of the part in question.

5.5.3 Length of Planning Horizon

The longer the span of the planning horizon the greater degree of forward visability. Any order, planned for in the latter portion of the tentative region, can be replanned, for in the span of the tentative region without causing any changes to the requirements plan. Changes in customer orders, available capacities etc. may all be replanned for when the planning horizon is short, the firm portion will constitute the largest portion, causing any changes to occur, within the requirements planning section.

5.6 INPUTS TO MRP

Irrespective of the name/type of MRP System in use, system always require three basic inputs.

5.6.1 Bills of Material (BOM)

As explained previously, MRP differs from other inventory control systems, because of its inherent ability to take dependant demand of individual items into account. This ability stems from the incorporation of a Bill of Material (BOM) into the MRP System. In order for MRP to produce valid results, the Bill of Material must be: - accurate, up to date and unambiguous. Bills of Material always originate with the design engineer, who is not be too concerned in the problems which are faced by production, and inventory control people, and so Bills may require some restructuring before being input to system. This restructuring is termed modularization.

Modularization techniques may be applied to some extent in all Bills. It has particular application however in cases where the product line consists of virtually unlimited number of end product or configurations, due to complex design and end product variations.

Six types of Bills are discussed below:

1. Engineering Bill:

   - The Bill of Material as presented by the Design Engineer.

2. Modular Bill:

   - The Bill is rearranged, as groups of items, which can be planned for together. When many product options exist the Bill needs to be modularized to facilitate forecasting, master production scheduling etc. and also to prevent stockpiling. Looking at product x y z, Fig. (5.2 a, b) it is inconceivable to maintain 3456 Bills for same basic product. It is possible to define 3 models, under option 1, or 6 under options I,J. Together, making a total of 576 options, and so on. Irrespective of the number of models and options, it is always much easier to forecast by basic product, and option then solely by options.

3. Planning Bill:

   - Term given to type of modular bill discussed in previous section.

Product XYZ	
Component Parts	Options Available
A	a_1 a_2 a_3
B	b_1 b_2 b_3
C	c_1 c_2
D	d_1 d_2
E	e_1 e_2
F	f_1 f_2
G	g_1 g_2
H	h_1 h_2
I	i_1 i_2 i_3
J	j_1 j_2

gives 3x3x2x2x2x2x2x3x2=3456 possible bills

Products	Fixed Options
XYZ_1	i_1 j_1
XYZ_2	i_2 j_1
XYX_3	i_3 j_1
XYZ_4	i_1 j_2
XYZ_5	i_2 j_2
XYZ_6	i_3 j_2

gives 576 bills

Example of Planning Bill Fig.(5.2)

4. Manufacturing Bill:

   - These Bills are not used for the purposes of requirements planning, only for final assembly scheduling. The items defined in the Bill are built using components provided by requirements Planning Bills. When orders are entered into system, Planning Bills generate orders, for lower level components, but he actural Bills for these assemblies have been removed and must be retained in an M-Bill file to facilitate final assembly scheduling.

5. Pseudo Bills of Materials:

   - Modularisation results in unique groups of items which must be forecast at MPS level in order to facilitate scheduling these groups of items must be assigned a parent, and the resulting Bill is termed a Pseudo Bill.

6. Phantom Bills:

   - A Phantom or "Transient" sub assembly is a subassembly which is immediately consumed by its parent the problem of phantoms only arise, when dealing with customer returns, over-runs etc. The technique of dealing with such items requires maintaining the item within the overall Bill, but assigning it a lead time of zero, and also include a special code within the Bill, so that the system can identify it as a phantom, and afford it special treatment.

5.6.2 Master Production Schedule (MPS)

The manufacturing activity starts and ends with customer orders. The master production schedule, is a statement of the planned build schedule, (inclusive of customer orders) in an ordered fashion. Demand, is specified, in terms of highest level items, in the previously discussed time periods, over the planning horizon. The MPS therefore has a matrix structure.

For the purposes of MRP the MPS may be regarded as a formal plan of production. It is a mixture of both customer orders etc. and forecast demand. The planning horizon may be divided into two distinct regions.

1. Firm Region.
2. Tentative Region.

The span of the firm region is determined by the cumulative product lead time, and represents committment to manufacture. Often this portion is guaranteed by the customer, its length indicates the trend towards Make-To-Order (MTO). The remainder of the planning horizon is made up of forecasts. The input to MRP may take the form of both the firm portion and some or all of the tentative region. However only the firm region is required for order release. Together they may be used for capacity planning etc.

If the MPS initiates the manufacturing process by introducing customer demand into the process, the final assembly schedule (FAS) completes the circle, by ensuring what is produced is in fact what is required. Often confusion arises between the two. When the product line is relatively simple, and the number of components is quite small, the MPS and FAS are identical. They are also identical, in the case of highly complex MTO products. The disparity arises in products which fall in the middle of these two groups.

5.6.3 <u>Inventory Record File</u>

These files also called the item master, contains much information, relating to each and every item contained in the Bills of Material. Data, may be divided up into two main sections for the purposes of MRP.

1. Planning Factors: - Lead times, safety stock, lot sizes etc., anything which is static in the system, and effects requirements generation.
2. Status Data: - The type of status data, manintained is dependant upon the system in use. Net change systems maintain status data, in its most broad sense, ie., gross requirements, net requirements, are updated within the file. Regenerate systems however, will only maintain status data, in the narrow sense, on hand, and allocated amounts. Record balance, and interlevel equilibrium, therefore only applies when status datails maintained in its most broad sense.

Record Balance and Interlevel Equilibrium

An individual item record is said to be in balance, when:

1. The on-hand inventories in each time period correspond to existing gross requirements and scheduled receipts.
2. Planned orders are correctly determined as to both quantity and timing.

Inventory transactions will cause the program to both update the file and generate requirements. This triggers of an explosion of transactions, the sole purpose of which is to update records, and maintain balance, within levels. Interlevel Equilibrium - is just an extension of record balance to include items which are logically related. Gross requirements for every item, must correspond at all times to the quantities and timing of planned order releases of its parent items. If, a change occurs in the value or timing of say a scheduled receipt (open order), this then causes a change in the net requirements, and ultimately a change in planned order release. Assuming this item, is made up of component items (decendants), a change will necessarily occur, in the gross requirements of the component. This net change, is immediately reprocessed, and interlevel equilibrium restored.

5.7 MRP AND SYSTEM NERVOUSNESS

An MRP system is a very complicated information system. It relys heavily on up to date, information, and because of this, continuous replanning is a necessary feature of any system. Replanning requires the frequent description of open orders (scheduled receipts), in an effort to keep the system up to date, with real world events. This gives rise to certain internal pecularities and operating problems, generally referred to as system nervousness.

> "Significant changes in MRP Plan, caused by minor changes in MPS or at higher product structure records".

System nervousness can effect both the quantity and timing of planned and open orders and may be triggered by lot sizing.

CHAPTER 6

LOT SIZING AND MRP SYSTEMS

6.1 INTRODUCTION

The entire MRP philosophy, rests on interdependencies that exist between item (components) in both the vertical and horizontal planes. MRP systems offer a variety of lot sizing techniques, which can be selected and implemented easily, at any level within the product structure.

What exactly is Lot Sizing? -It is a formal procedure involving the combination of order requirements in adjacent time periods in order that a trade-off between inventory holding costs and order (set-up) costs may be achieved. Lot sizing techniques, may be of two types.

1. Static
2. Dynamic

However, the only truly dynamic method of lot sizing is said to be the lot for lot method whereby in fact, no lot sizing procedure is called upon to tamper with MRP requirements. Static methods however, applied at various levels within the product structure, cause, an increase in requirements at lower levels, which magnifies as you continue down through the structure. This is just one of many aspects of MRP system nervousness (See Chapter 5). Orlicky [32] defines the following factors as affecting the relative effectiveness of all lot sizing procedures.

1. Variability of demand
2. Length of planning horron
3. Size of planning period
4. Ratio of set-up and unit costs.

Browne [5], Orlicky [32], Berry [48], agree, that no lot sizing procedure presently on offer is any better than any other, when applied to a specific manufacturing environment.

The static approach to lot sizing may possibly be considered to be a series of local solutions which do not solve the global problem. One of the reasons for this is the total preoccupation of lot sizing techniques with trying to justify set-up costs. Burbidge [29] says on this topic:

> In many ways the simplest argument against the Economic Order Quantity (EOQ) is that it solves the wrong problem. The EOQ theory states that if set-up times are long, one should make in large batches, to spread set-up costs. A better argument is that if set-up times are too long they should be reduced".

If MRP systems, are to continue to play as an important a role, in western manufacturing systems in the future, an attempt must be made, to find an optimal solution to the lot sizing problem.

6.2 COMMON LOT SIZING PROCEDURES

6.2.1 Assumptions

The following section describes a number of lot sizing procedures, generally found in MRP packages. These procedures are all relatively simple to apply, and at the time of their application, a number of assumptions must be made.

1. Requirements generated in a particular period, must be available, at the beginning of the period.
2. All requirements must be met in a period for a future period, they cannot be back ordered.
3. Ordering decisions assumed to occur, daily/weekly i.e. at regular time intervals.
4. All requirements are assumed to be properly offset for manufacturing lead times.
5. Component requirements met at a uniform date during each period. Therefore, an average inventory level used, in computing inventory carrying costs.

Table(6.1):Comparison of Lot Sizing Procedures.

Lot Size procedure.	Advantages.	Disadvantages.
Economic Order quantity	1. Easy to apply	1.Method evolved from the idea of constant uniform Demand. 2.Fails to take account of trends in requirements. 3.No account taken of inter-item dependency.
Period Order Quantity.	1.Easy to apply. 2.Tends to Reduce Carrying Costs.	1.Fails to take account of trends in requirements. 2.Fails to take account of inter-item dependency. 3.Orders preconstrained to appear in set time periods.
Lot-for-Lot.	1.Truly Dynamic. 2.Simple to apply	1.Any cost variations are ignored. 2.Trends in requirements do not impact on order policies.
Part Period Total Cost.	1.Tends to reduce carrying costs. 2.Permits both lot size and timing to vary.	1.No account taken of dependency. 2.Not necessarily optimum solution, all options not evaluated. 3.When requirements are large disintegrates to Lot-for-Lot.
Wagner-Whitin.	1.Can accomodate Varying costs. 2.Never degenerates to Lot-for-Lot.	1.Requires more data Processing than any other technique. 2.Results may be Ambiguous. 3.Ignores trends in Production quantities.

When applying lot sizing methods a distinction must be made between, manufactured and ordered parts. Price discounts can serve to complicate the situation.

6.2.2 Lot Size Decision Policies

The Lot-For-Lot method of lot sizing is the most direct method available today. Generated requirements are translated into order quantities without recourse to any calculations to economically "improve" the lot size. This rather simple method however, has a number of inherent problems. Firstly, if costs were to vary across the planning horizon, no account would be taken of this variation, and opportunities to produce more cheaply would be missed. The number of actual orders generated equals exactly the number of periods in which requirements were generated possibly resulting in a large number of orders, of varying sizes at quite frequent intervals.

Often requirements are generated in quantities which the supplier cannot supply. This may arise in cases where containers, or weight measurements are used to supply materials. Generating requirements at this stage, without performing some Lot sizing procedure would cause immediate problems. Some lot sizing procedures have the ability to compensate for trends in requirements, adopting suitable ordering policies, dependant upon the variation of magnitude of requirements. The Lot-For-Lot method, by ordering exact requirements generated, fails to do this.

Economic Order Quality

One of the first lot sizing policies to be introduced was the economic batch size policy. It is also one of the more widely used and accepted methods. The equation below describes the technique.

$$EOQ = \sqrt{\frac{2 \times P \times D}{HC}} \qquad (6.1)$$

P: Order Costs.

D: Average Period Demand.

HC: Holding Cost.

An average demand is calculated over the span of the horizon, and an attempt is then made to mimise costs by combining requirements. A static Lot size is determined, and a number of periods demand can then be met from the produced lot. If however requirements within the planning horizon are quite varied, some single period requirements may be greater than the lot size, and an order decision policy must be made based upon two alternatives.

1. Multiples of the economic batch size may be ordered.
2. The economic lot size may disintegrate to Lot-For-Lot.

If the first alternative is adopted, actual production may increase way beyond requirements, the second alternative compounds any adverse effects due to employing the EOQ policy by simultaneously operating a Lot-For-Lot policy.

<u>Period Order Quantity</u>

This method is a variation of the fixed order period method. It demonstrates an attempt to keep inventory carrying costs at a minimum. An economic time interval is calculated, based upon average, demand and economic order quantity, - attempting to spread the batch size over a number of periods.

$$\textbf{Economic Time Interval} = \frac{\textbf{Economic Batch Size}}{\textbf{Average Demand}} \qquad \textbf{(6.2)}$$

The procedure, then calls for ordering exact requirements over the interval. Carrying costs figures may therefore be improved assuming fairly uniform demand, but large variations in demand may continue to incurr high carrying costs. The method has a number of similarities, to the pervious method in that any trends in requirements are totally ignored, and no account is taken of the dependency between items. Unlike the EOQ method however, orders are constrained to appear in preset time periods a set number of periods apart, thereby preventing any capitalization on cost variations in differing periods.

Part Period Balancing

This method also stems from the economic order quantity. It represents an attempt to equate set up costs with the cost of carrying inventory. All information provided by the requirements schedule is used. This required that the carrying cost involved, when placing an order in period T for a period span of T+N must approximate the cost of placing that order.

Examining the alternatives.

A. Place an order, in period T for period T,S requirements along:

$$HC \text{ X } [\tfrac{1}{2}(R_{it})] = HC^1 \quad (6.3)$$

B. Place an order in period T for period T, and T+1 requirements alone

$$HC \text{ X } [\tfrac{1}{2}(R_{it}) + 3/2\ (R_{it+1})] = HC^1 \quad (6.4)$$

C. Place an order in period T for periods T, T+1, T+2..... T+N requirements.

$$HC \text{ X } \{\tfrac{1}{2}(R_{it}) + 3/2\ (R_{it+1}) \ldots ((2N-1)/2)\ (R_{i,t+N})] = HC^1 \quad (6.5)$$

Where HC: Holding cost/period; HC^1 total holding cost, R_{it}; Requirements, item i period t.

When the holding costs, that would be incurred by placing an order in period T, to cover the demand for N periods, approximates the order costs incurred, the lot size is chosen to cover all previous requirements.

The Least Unit Cost (LUC)

This lot size model is based upon order and inventory costs. It may also accommodate price break decisions. Requirements are accumulated over time periods, and the total cost associated with placing the order in an earlier period evaluated, until, the price per unit begins to increase. The policy which results in the smallest cost per unit is then chosen.

Examinging the alternatives.

A. Placing an order in period T, to.cover the requirements in period T alone.

$$\text{Total Cost Per Unit} = [(R_{it}) \text{ x PP} + SU]/(R_{it}) \quad (6.6)$$

B. Placing an order in period T to cover req. in period T, T+1

Total Cost Per Unit $=$ [HC x (R_{it+1}) + $(R_{it} + R_{it+1})$ x PP + SU]/ $(R_{it} + R_{it+1})$ (6.7)

C. Placing an order in period T to cover req. in Period T, T+1 T+N

Total Cost Per Unit $=$ [(HC x (R_{it+1}) + HC^2 x (R_{it+1}) ... HC^N x (R_{it+N})) + $(R_{it} + R_{it+1} + \ldots R_{it+N})$ x PP + SU]/$(R_{it} + R_{it+1}$ .....$R_{it+N})$ (6.8)

Where PP: Production costs; SU: set-Up Costs.

If order policy C results in the lowest unit costs, it is then chosen to cover requirements in period T to T+N, and the order is placed in period T. The next order will then be placed in period T+N+1.

Least Period Cost (LPC)

Same method as that of least unit cost, except that the criteria for chosing the lot size is changed. Least period cost (LPC) uses the lowest cost per period, rather than per unit to determine the lot size. Once the various policies have been evaluated, the policy which incurrs the least average period cost is chosen, to cover N periods. The next order will then be placed in period T+N+1.

6.3 MATERIAL REQUIREMENT PLANNING MODEL

6.3.1 Introduction

Based upon the work of Zahorik et al [15], Billington et al [16], who developed linear programming formulations for the series system in parallel, and general assembly case respectively. The following three dimensional material requirement planning lot size model has been developed.

The model seeks to minimize total costs, accumulated during production. These costs, are made up of both production and holding costs. Set-up costs are completely ignored by the model for two reasons.

1. They are assumed to be relatively small in comparison to production costs.
2. As companies become more aware of Just-In-Time (JIT) techniques, the emphasis will be on the further reduction of these costs.

The model allows costs to vary from period to period and in do doing account for eventualities, such as overtime/undertime, variations in skill levels etc. Costs are assumed to be linear.

External demand is assumed to be deterministic, and to occur, for each product at the end item level. The span of the time periods, and their individual length (time) will be as specified in the master production schedule (MPS), and will therefore be finite.

No backlogging of orders will be allowed. This requires that production in any period, may be to satisfy demands made in future periods, but not those made in previous periods. This requirement is in keeping with the master production schedule, (MPS), which sets out demand figures from the present time to some specific time in the future. If backorders were required, it would be up to the master scheduler to accommodate them within the confines of the MPS.

The model itself, will have three subscripts, the first used to indicate the product, the second the level at which the item occurs, and the last relating to the time period. Final products, ($i = 1..N$) will occur at level $j = 1$, in all (or none), time periods. The suffix j is also a level index, but is used to represent parent items, ie. items on levels higher than the one in question.

Production is not assumed to occur instantaneously, production lead times are included in the model. Production of any parent item, due to be completed, in a time period t, with a lead time L, requires that component items are ready in a time period T-L, in order that assembly be completed on time.

The general form of the MRP product structure depicts items with both multiple parents (ascendants) and multiple descendants. Multiple descendants can be dealt with, in the conservation of flow matrix, the difficulty arises in dealing with multiple parents.

6.3.2 Statement Of Assumptions

1. Deterministic External Demand.
2. Finite Planning Horizon.
3. No Backlogging Of Orders.
4. No Set Up Costs.
5. Linear Production Costs.
6. Constant Production Lead Times.
7. Any Item can have no more than on Parent (only on descendant).
8. Each product (k) must go through a similar sequence of events.

6.3.3 Nomenclature

1. Subscripts

   $k = 1....M$ Product Index

   $i = 1....N$ Component Item Index

   $t = 1....T$ Planning Periods

   $j(i) = 2....N$ Parent Item Index

2. Constants

   C_{kit} Unit cost of production, product k, item i, period t.

   H_{kit} Unit cost of holding inventory item i, product k, period t.

   D_{kit} External demand, product k, item j, period t.

   $L_{(ki)}$ Production lead time for item i, in product k.

3. Decision Variables

I_{kit} — Inventory at the beginning of the time period. By virtue of the fact that no events can occur in between time periods, this inventory is equivalent to that available at the end fo the previous period.

P_{kit} — The production of product k, item i, which becomes available, at the beginning of period t.

D_{kit} — The external market demand of product k, item i, in period t.

6.3.4 Model Formulation

1. Minimise

$$\sum_{kit} C_{kit} P_{kit} + \sum_{kit} H_{kit} I_{kit} \tag{6.9}$$

2. Subject To

$$I_{kit-1} - I_{kit} + P_{kit} - \sum M_i P_{kj(i)\,t+L_{k(j(i))}} = D_{kit} \tag{6.10}$$

6.3.5 Discussion Of Terms

Equation (6.9) states the objective of the model formulation which is to minimize the production costs, for every product, at each and every item level, and in every period. Holding costs incurred, during the same time periods must also be minimised.

Equation (6.10) is termed the flow conservation matrix, and governs the flow, of material from one production stage to the next. Consider product k, item i, in period t. The first term of the equation relates to inventory held, for item i at the beginning of period t. (I_{kit-1}).

The second term represents inventory left at the end of period t. This inventory is obviously going to be the net of the initial inventory and any events or actions which take place during that time period and have an effect on the inventory on hand figure (I_{kit}). These events, are summarised by the next three terms.

The third term relates to production of product k, item i, period t which is due for completion at the beginning of period t. This production will serve to increase the on hand quantity (P_{kit}).

The forth term relates to internal demand - demand which has been derived from internal dependencies between items. M_i, refers to the quantity of item i, required per the production of one unit of the parent item j(i). If the production of one unit is going to become available at the beginning of period t + L $_{(j(i))}$, where $L_{(j(i))}$ refers to the lead time of assembly of the parent item, then the quantity of item i, must be removed from inventory, during period t. This serves to reduce the on-hand amount held in inventory. (Σ M_i $P_{kj(i)t+L(j(i))}$)

The final term, refers to external demand. External demand, demand from the market, is satisfied instantaneously, if no time lag occurs between the requirement, and fulfillment, both happen within the same time period. (D_{kit})

6.3.6 Model Representation

The model can be represented in terms of a three dimensional matrix structure as follows:

1. Each individual product is represented, successively parallel to the page (k = 1..M)
2. Time Periods (t = 1..T), runs down the page, in successive sections, each section corresponding to an item, in the product structure, giving T x N Rows.
3. The inventory held and production carried out in the various time periods, for each item, are represented, by the columns, advancing

across the page. This results in 2 x T x N columns. In total therefore we have a three dimensional matrix, with, M x TN x 2 TN Entries.

NOTE the j axis, or columns also represents the various levels within the product structure, dependent upon the number of items within each level.

6.3.7 Introducing Item Planning Horizons

Although the number of columns in the matrix is generally defined to be 2 x T x M this number can be reduced by introducing the idea of a production horizon for each and every item, within the product structure. This is done by letting the production horizon for the product k, item 1, (ie. top level item) equal to the span of the planning horizon as specified in the master production schedule.

$$R_i = T \qquad (6.11)$$

The production horizon for all items at lower levels are then determined alternatively, using both the production horizon and lead time for assembly of parent items.

$$R_{ki} = R_{kj(i)} - L_{kj(i)} \qquad i = 2....N \qquad (6.12)$$

No production can take place, after $R_{ki,}$ and this ensures that all items produced, will be done so in a time period which allows their inclusion in a proceeding sub-assembly.

In keeping with this idea of timing, no production is allowed to appear in a given period until, a number of time periods, equal to the lead time of that item has passed.

$$P_{kit} = 0, k = 1..M, i = 1..N, t = 1..L_{ki}$$

No initial inventories are allowed, at any stage of the production process, and once the duration of the planning horizon has been completed, inventories cannot be held into the next time period as they cannot be used in further sub-assemblies ($t \geq R_i$).

$$I_{kio} = 0$$

$$I_{kit} = 0, k = 1..M \ i = 1...N, t \geq R_i.$$

This leaves the model, with the following qualifying constraints.

1. $P_{kit} = 0, k = 1..M, i = 1...N, \ t = 1...L_{ki}$

2. $I_{kio} = 0$

3. $K_{kit} = 0 \ k = 1...M, i = 1...N \ t \geq R_i$

6.3.8 Final Model

The model becomes

1. Minimise

$$\sum_{kit} C_{kit} P_{kit} + \sum_{kit} H_{kit} I_{kit} \qquad (6.13)$$

2. Subject To

$$I_{kit-1} - I_{kit} + P_{kit} - \sum (M_i P_{kj(i)\,t+L_{k(j(i))}}) = D_{kit} \qquad (6.14)$$

$k = 1..M, \ i = 1..N \ t = 1...R_{ki}$

$P_{kit} = 0 \quad k = 1..M, i = 1..N, t = 1..L_{ki}$

$I_{kio} = 0$

$I_{kit} = 0 \ k = 1..M, i = 1..N, t \geq R_{ki}$

6.3.9 The Model And Networks

A generalised network is a type of linear programming problem, and therefore can be solved using any standard linear programming solution technique. The primary reasons for adopting network formulations are.

1. The superior efficiency of generalised network codes.
2. The pictorial presentation, is a useful explanatory device.

In terms of matrix representation a generalized network may contain at most two non zero elements, per column, ignoring the upper bound constraints. When these non zero elements correspond to $\pm$ 1, the network is termed a pure network, examples include, transshipment, transportation, assignment problems. If the generalised network structure is not immediately apparent sets of linear transformations may be employed to produce it.

The one dimension counterpart of the model matrix formulation is not itself a network, however, it may possibly be solved using, decomposition technique, or as a network formulation with side constraints. Advances in parallel processing will aid the solution of the 3-D model.

6.3.10 Model Simplifications

At the present time, the model described in the previous section is difficult to solve. The reasons for this fall into two main sections, firstly those pertaining to computer processing capability, and secondly, those pertaining to mathematical programming capability.

Mathematical Programming

Linear programming methods in use today are very time consuming, especially when branch and bound methods are used to solve integer linear problems. Because of this, various other solution methods are being sought. Attention has been focused on developing generalised network codes, to solve the linear programming problem.
When the model described in the previous section, is restricted to be 1 in the k axis, (ie. 1 product), the matrix, when considered in its complete form, does not exhibit network properties, firstly because some components have common parents, and secondly because, parent items may require more than one component. Decomposition methods, - which allow the determination of the optimal solution, by first decomposing the problem into smaller sub problems, and then solving the subproblems almost independently, may possibly be used to exploit the definite block structure of the problem, in conjunction with network solutions.

At the present time however network solutions only apply to single parent single component problem (ie. series case). To solve, the general assembly case, linear programming methods, such as the simplex, or Big-M technique must be used.

Computer Processing

The computer processing capability required to solve the multi product case, would be large, and very time consuming. This is because present day computers only have one processor - The central processing unit - single processors are suited to solving the single product case for up to 1000 components, assuming the matrix is triangularised (Ho et Al [17]). Investigation into the use of computers in parallel and therefore, parallel processing which allows data to be input and manipulated very quickly is ongoing. Use of minicomputers having 2^N parallel processors are becoming increasingly cost effective ($N = 6$-8). The problem associated with the amount of data to be manipulated can best be seen by example. If a particular company has a product range of 100 items, each with 100 components, and operates from a planning horizon of 10 periods, then the no of constraints or equations to be considered would be

$$\underset{\text{period}}{10} \quad \times \quad \underset{\text{product}}{100} \quad \times \quad \underset{\text{items}}{100} = 100{,}000 \text{ constraints}$$

and

$$2 \times 10 \times 100 \times 100 = 200{,}000 \text{ variables,}$$

assuming production and inventory decision variables for each item.

Attempting to solve problems of this size, on todays computers is impossible.

Model Simplifications

In order to investigate the model presented, the following modifications will be made.

1. Only one product will be considered.
2. The product, may only have components, on up to 5 levels.
3. The lead time for individual production processes is restricted to 1.

4. In order that the actual optimization ability of the solution technique can be appreciated production costs will vary both per item, and across the planning horizon.
5. Inventory holding costs will vary per item but no across the planning horizon.
6. Demand patterns will be constrained to occur in 6 different ways. A) Level B) Lumpy C) Increasing D) Decreasing E) Concave F) Convex.
7. The product may have up to 8 components spread over the 5 levels.
8. The model will be investigated over a planning horizon of 6 or 12 periods. (Max cumulative lead time of product is 5).
9. Each item may only have one parent.

Minimise

$$\sum_{\substack{i=1\\t=1}} C_{it} P_{it} + \sum_{\substack{i=1\\t=1}} H_{it} I_{it} \qquad (6.15)$$

Subject To

$$I_{it-1} - I_{it} + P_{it} - M_i P_{j(i)\,t+1} \qquad (6.16)$$

1. $i = 1..5$, $t = 1...12$.
2. $P_{it} = 0$ $i = 1..5$, $t = 1$.
3. $I_{io} = 0$
4. $K_{it} = 0$, $i = 1..5$, $t \geq R_i$

NOTE $R_1 = 5$

$R_i = R_{j(i)} - L_{j(i)}$ Planning Horizon

$R_i = R_{j(i)-1}$

6.4 SOLUTION METHODS

6.4.1 Linear Programming (LP)

Introduction

In its standard form, the linear programming form of a mathematical model consists of an objective function, which must be maximised, (or minimised) and a number of constraint equations, each with non-negative Righ Hand Sides (RHS). All equations, in the model must be linear, which requires that:

1. The contribution of any variable in the objective function be directly proportional to that variable valve, ie. price breaks, discounts etc., do not belong to the LP class of problem.
2. The objective function be the direct sum of individual contributions of the different variables.

When all the constraint equations are plotted graphically, the area bounded by the equations is referred to as the feasible solution space. Each point on or within the boundary to the solution space, satisfies all the constraints, and represents a feasible solution. The optimum solution however, can be determined by observing the direction which maximizes (or minimizes) the objective function, if the line representing the objective function is moved in this direction, along a line 90° to it, until any further motion renders the objective function line outside the feasible region, then the optimun value of the objective function has been found. The values of the variables required, to give this optimum solution are then found by solving simulataneously the constraint equations which intersect at this optimum point.

6.4.2 Simplex Method/Algorithm

A distinction must be made between the simplex algorithm, and the simplex method. The simplex algorithm describes the actual solution method whereas the method encompasses both the method and the transformation from the initial linear programming model, with enequality constraints to the format required by the simplex algorithm.

If a constraint is of the form ($\leq$), then in order to make the LHS equal the RHS a certain slack variable S, must be added to the LHS. Alternatively, if the constraint is of the form ($\geq$) then a slack variable must be subtracted from the LHS. All the slacks must also be constrained to be non negative. Once all the inequalities have been reduced to equalities, the model is in the form required by the simplex algorithm.

The algorithm is an iterative procedure, which starts at a feasible corner point, and systematically moves to the next adjacent corner point, until the optimum point is reached. The only rules required are:

1. Must move to an adjacent solution space.
2. You cannot regress.

The simplex method deals only with points on the boundary, called extreme points because the optimal solution will always be on the boundary. At every extreme corner point, two types of variables exist.

1. Non basic variables.
2. Basic variables.

Non basic or zero variables, are those variables which do not appear in the solution at that point. Adjacent extreme points differ by only one variable, in time basic (non zero) solution set. The variable which enters the basic solution, is called the entering variable, and the variable which leaves the basic solution to join the set of non basic variables is called the leaving variable. The choice of entering and leaving variable is an integral part of the simplex algorithm. The entering variable is usually that variable, which by increasing its value above the zero level, will achieve the greatest increase in objective function value, at the next iteration. Conversely leaving variables are chosen because, when, the entering variable reaches its maximum value, at the adjacent extreme point, the leaving variable will be the first to reach zero.

6.4.3 Method of Penalty

The method of penalty technique, refers to the actual setting up of the problem LP, so that it can be solved by the simplex algorithm. The simplex algorithm always assumes, a starting basic solution, (usually equivalent to the slack variables). However, if one or more of the constraints are not inequality constraints, then, the number of slacks, will not equal the number of equations and it is difficult to decide, what variables should be set to zero. The method of penalties introduces the idea of artificial variables.

When all inequalties have been removed artificial variables R_i are added to the LHS of any equations which do not have any slack variables. By assigning these variables very small (maximise) or very large (minimize) positive coefficients in the objective function they will eventually be forced to zero. The starting feasible basic solution will then consist of any slack variables plus any artificial variables, and the non basic variables, of surplus and expected final solution basic variables. The simplex algorithm can therefore complete normally. Note, the Linprog 2 package referred to in this chapter, uses the penalty method, to set up the relevant LP.

6.4.4 Branch and Bound Method

Branch and Bound Methods apply to both pure (all variables non-negative) and mixed (some variables non-negative) problems. The general idea behind the method is to firstly solve the program as an LP and then restrain any non integer values to be integers, and solve the resultant LP's. If X_r is found to be non integer, restraining Xr, over the interval

$$[X_{r^\bullet}] \leq X_r \leq [X_{r^\bullet+1}], \tag{6.17}$$

Results in two subproblems. By enforcing integrality, the branching strategy reduces the size of the feasible solution space. Each problem can then be solved as an LP using the same objective function. If the solution is found to be feasible, and integer, and the value of the objective function smaller than any previous value, the solution is accepted as the best available bound. Any branching which results in a non-integer, solution, and has an objective function value less than the best bound, is not branched from again.

6.4.5 Introducing Inventory To The Model

The model as stated in the previous chapter is not complete. No inventory has been introduced to the model, and therefore none will reach the various demand nodes, when the model is input to the computer. Two methods exist whereby inventory can be introduced.

The first entails accumulating all end item demand across the span of the planning horizon, and letting the sum of the production at the end item facility equal to this accumulated production. The equation below summarizes this technique (i=1).

$$\sum_{t=1}^{T} P_{it} = \sum_{t=1}^{T} DEM_{it} \tag{6.18}$$

This allows the model to work out the cheapest production pattern at end item level before proceeding further.

The second method requires the introduction of initial inventory to the model in time period zero. This initial inventory must be greater than or equal to the accumulated demand across the span of the planning horizon at end item level. This is summarized by the equation.

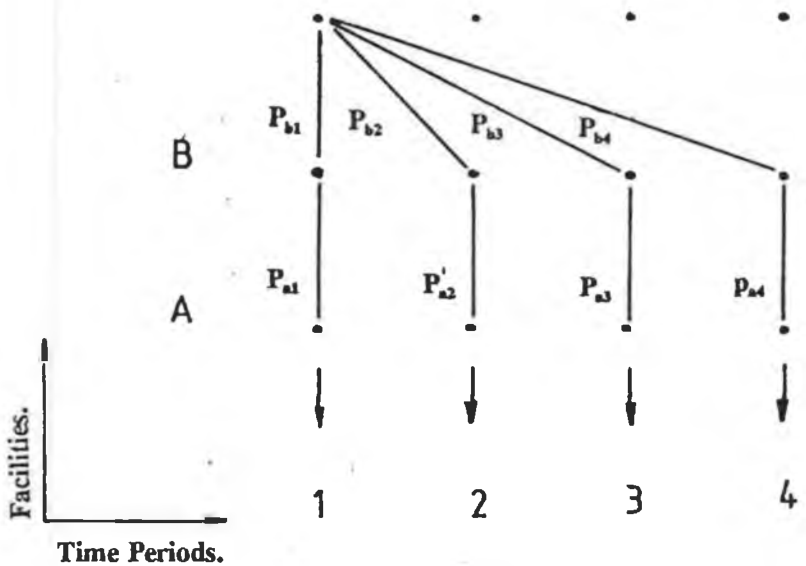
$$I_{10} = \sum_{t=1}^{T} DEM_{it} \tag{6.19}$$

If the initial inventory requirements are not sufficient to satisfy demand, the model will not run successfully. Table (6.3) compares the relative merits of both techniques, for a three facility assembly model, with varying production costs and constant holding costs. Table (6.4) defines the cost structure for the model.

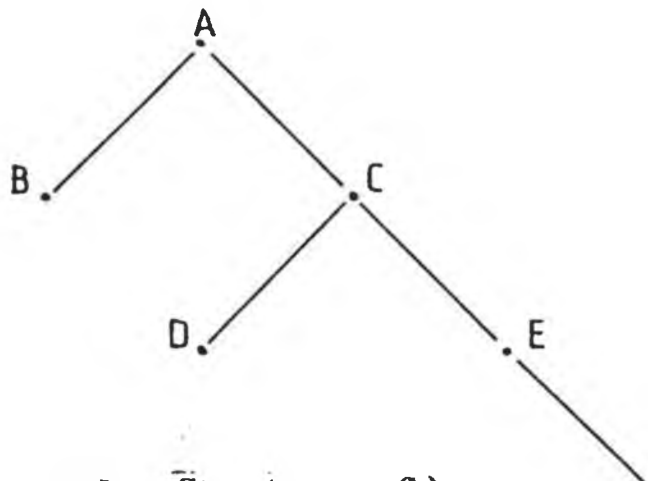
TABLE (6.2): Comparison of both methods of Inventory Introduction

	No of Iterations	Solution Time (Sec)	Obj. Function
METHOD 1	22	.4	80
METHOD 2	25	.45	80

The first method has advantages when dealing with the development of an MRP II type model, because the equation (6.18) can be used to constrain production at individual facilities to a number of planning periods and so introduce a capacity

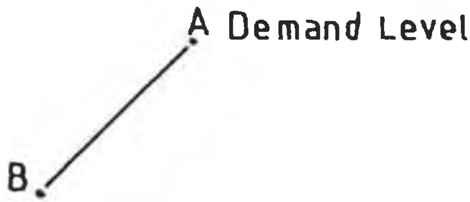


Network Diagram (a)



Product Structure. (b)

Fig(6.3)



Product Structure.

Fig (6.2)

TABLE (6.4): Variables for Model described in Fig. (6.2)

Planning Period	1	2	3	4
Dem. Pattern	1	1	1	1
P COSTS Item A, B	4	3	2	1
H Costs Item A, B	2	2	2	2

TABLE (6.3): Production and Holding Cost Pattern For A 3 Facility Model

Planning Period	1	2	3	4	5	6
(ITEM 1) PCOSTS	12	10	8	6	4	2
(ITEM 2) PCOSTS	10	5	1	1	5	10
(ITEM 3) PCOSTS	1	5	10	10	5	1
(ITEM 1) HCOSTS	2	2	2	2	2	2
(ITEM 2) HCOSTS	1	1	1	1	1	1
(ITEM 3) HCOSTS	1	1	1	1	1	1
(ITEM 1) DEM	1	1	1	1	1	1

P COSTS: Production Costs

H COSTS: Holding Costs

DEM: Demand Pattern

planning dimension to the model.

6.4.6 Lot Sizing, and Modelling

Imagine a product structure of the type Fig. (6.2) manufactured over a planning period, of length four periods. The demand pattern, production costs and holding costs, are specified in Table (6.4).

The resultant constraint equations will then be defined in Eqns. (6.20 - 6.27).

$I_{AO} - I_{A1} + P_{A1} = 1$	(Prod. A Period 1)	(6.20)
$I_{A1} - I_{A2} + P_{A2} = 1$	(Prod. A Period 2)	(6.21)
$I_{A2} - I_{A2} + P_{A3} = 1$	(Prod. A Period 3)	(6.22)
$I_{A3} - I_{A4} + P_{A4} = 1$	(Prod. A Period 4)	(6.23)
$I_{B0} - I_{B1} + P_{B1} - P_{A1} = 0$	(Prod. B Period 1)	(6.24)
$I_{B1} - I_{B2} + P_{B2} - P_{A2} = 0$	(Prod. B Period 2)	(6.25)
$I_{B2} - I_{B3} + P_{B2} - P_{A2} = 0$	(Prod. B Period 3)	(6.26)
$I_{B3} - I_{B4} + P_{B4} - P_{A4} = 0$	(Prod. B Period 4)	(6.27)

No initial inventories are allowed, which required that $I_{A0,}$ I_{B0} are set to 0. If inventories were left over at the end of the planning horizon, additional holding costs would be incurred, and $I_{B4,}$ I_{A4} are also set ot zero.

There must however be some starting point, from which the program run originates, and because, it is the production lot sizes that interests us, an additional constraint, must be added, that specifies, the cumulative production requirements of the end product. (See Sect. 6.4.2).

$$P_{A1} + P_{A2} + P_{A3} + P_{A4} = 4 \qquad (6.28)$$

Using the production and holding costs for item A, as specified in the objective function, the package chooses the cheapest production plan. (Note the model has been established in such a way as to avoid back logging only forward production is allowed). The following alternatives would be considered, and one accepted.

(NOTE: Production costs are outside brackets, units produced are within brackets).

4(4)	=	16	Alternative 1
4(1) + 3(3)	=	13	Alternative 2
4(1) + 3(1) + 2(2)	=	11	Alternative 3
4(1) + 3(1) + 2(1) + 1(1)	=	10	Alternative 4

By requiring that production costs decrease, as the planning periods advance ensures the production requirements are generated as late as possible. Therefore, as production terms advance over the horizon, the amounts produced, can never be less than in a previous period, for example,

4(1) + 3(2) + 2(1), = 12, would not be considered.

When holding costs are taken into account (Alternative 1 would incurr a holding cost of (2(3) + 2(2) + 2(1) = 12 cost units). This cost pattern would lead to the acceptance of alternative four - production requirements generated to meet demand in the same period in which the demand occurs.

Once a production pattern has been decided upon, equations (6.20 - 6.27) are used to generate the amount of inventory held in each period. Item B'S production pattern is arrived at in a similar fashion.

6.4.6 Interpretation Of Results

The easiest way to interpret the results obtained is through the use of a single source network diagram. Time periods advance across the page and the various facilities downwards. Each node has an associated equation, and production requirements are defined downwards flowing into the various nodes (one for each period in the planning horizon). Inventory being held, is defined across the page from one node to the next. Fig. (6.3).

The problem associated with the use of single source networks to interpret results, is that, for each branch within the product structure, a new single source network diagram must be drawn. A product structure of the type described in Fig. (7.3) would require three diagrams, one dealing with, A, B, another with A,C,D and finally one dealing with A,C,E,F. This leads to much duplication of data.

6.4.7 Inclusion of Varying Planning Horizon

Again looking a the product structure in Fig. (6.2) assuming that the results obtained are going to be offset to include manufacturing lead times, then production of item B, should be stopped in a time period T_{max} - Lead time of A, anything produced in periods later than this can not be used in useful production of A. This results in a sort of rolling planning horizon.

Item A - Produced in four periods.

Item B - Produced in three periods.

Also connected with the idea of planning horizon, is that of final inventory. If the inventory, at the end of each planning horizon is not set to zero, then the possibility of being left with unused inventory arises. If both $I_{B3,}$ and P_{B4} are set to zero, then inventory items have no way of being produced at $P_{A4,}$ and the only way of satisfying demand is to produce at facility A, in period 3, and hold the item to satisy period four demand until period four. If it is cheaper to hold item, B than item A, then setting I_{B3} to zero is not the correct solution.

Examining the Eqn. (6.28), (ie. time period 4) for item B. It consists of items, which are known already and/or are set to zero, it can therefore be completed removed from the nodel. For any model therefore, as you advance down item level the no of equations can be reduced by the item level number less one.

6.4.8 Specific Models

This section slowly develops simple but specific models from the more general model discussed in section 3.

Each model is examined assuming a uniform market demand of four units spread equally over four periods. The inclusion of lead times however extends the planning horizon by an amount equal to the cumulative lead time of the product. Each model is discussed individually in relation to the following:

1. Arrangement of facilities.
2. Cost structure at each facility.
3. Results obtained, and their interpretation.
4. Arranging production schedule to account for lead times.

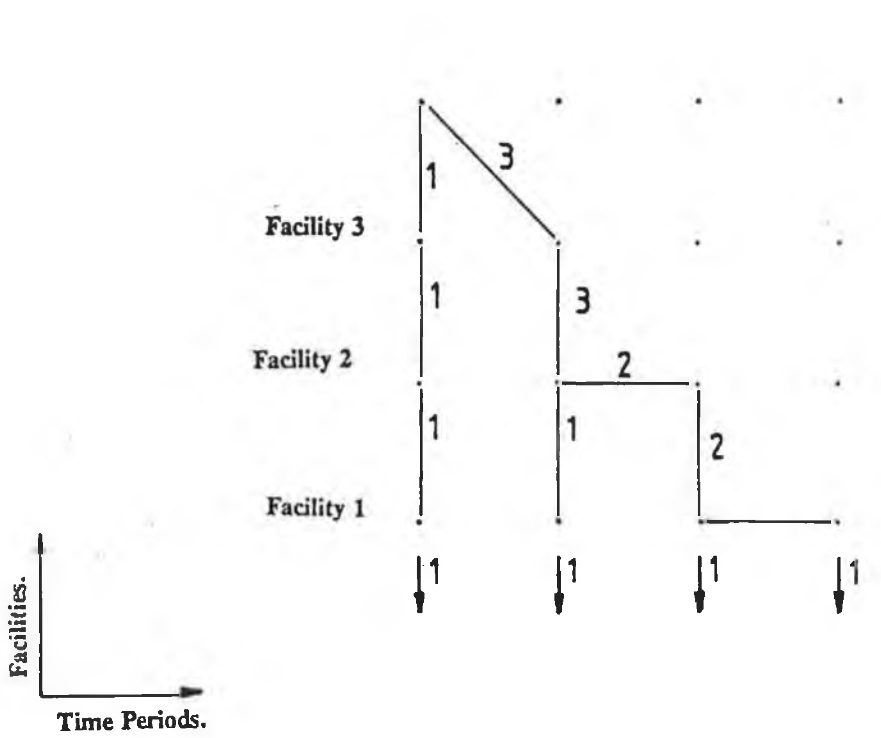
The package used to solve these models allows the data to be immediately input in standard data file form. The data file consists of the problem type, - maximise or minimise, the objective function, and all pertinent equations, each specified in terms of the appropriate variables.

Output from the package is also easily understood, consisting of the objective function value, those variables who have achieved final valves greater than zero, and their associated primal and dual values. Both the input and output file for each of these models are listed in the appendix (2).

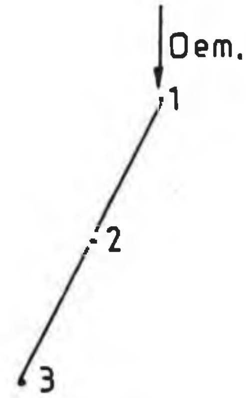
Three Facilities In Series

This first model consists of three facilities laid out in series. The raw material, which is introduced at facility three, undergoes three seperate processes, but no sub-assembly operation occurs. The end item is produced at facility one, and therefore all production at this point must satisfy market demand. The cost structure for each individual facility is defined in the objective function. In this case, all facilities have the same cost structure which decreases over the planning horizon to ensure items are processed as late as possible.

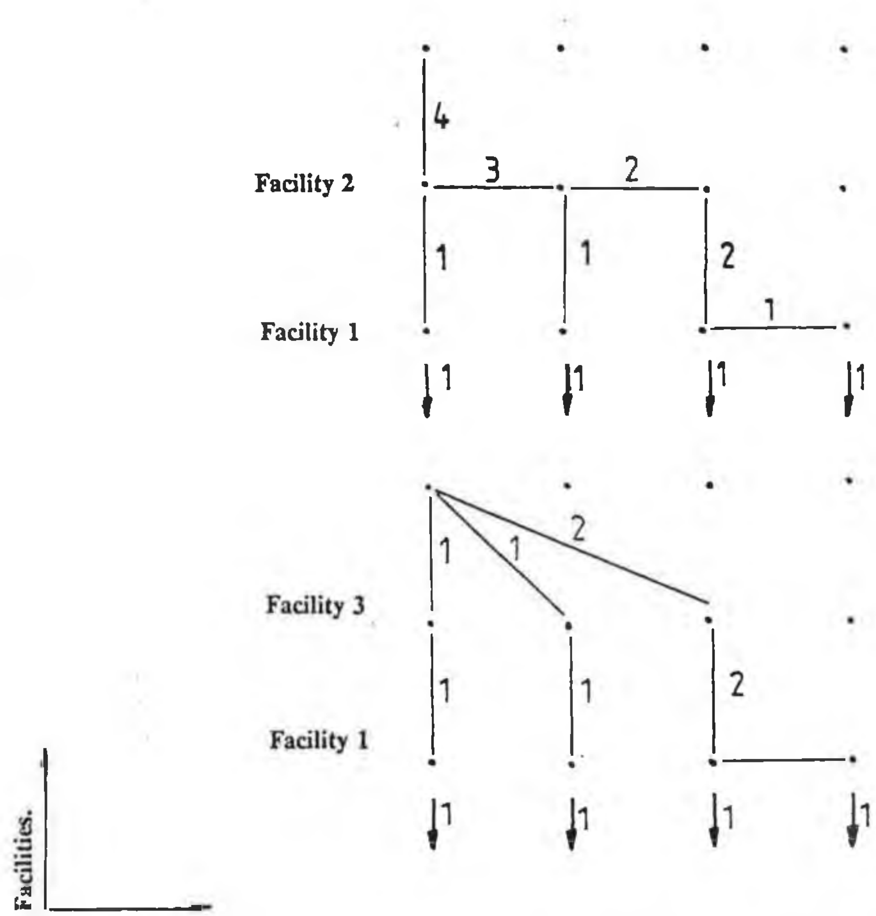
Four equations are required to specify material flow at facility one, implying production may take place in any one of four periods. Owing to lead time inclusion, only three equations are required to specify material flow at facility two. If production occurs in a fourth period it cannot proceed to facility one, and will remain as in process inventory. Similarly only two equations are required for facility three. Inventory in the final production period at each facility is set to zero, ensuring that anything produced in that final period will be processed at the next facility. The



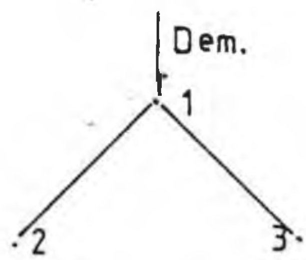
Network Diagram. Fig.(6.5b)



Product Structure. Fig.(6.5a)



Network Diagram. Fig.(6.6b).



Product Structure Fig.(6.6a)

model is represented graphically in Fig. (6.5a). A network interpretation of the solution is shown in Fig. (6.5b).

At the final facility, facility one, demand is specified as being uniform, with a magnitude of one in each period. The model specifies however, that any units processed, in the final production period in the preceding facility, must not be allowed to accumulate, in a suceeding period, the final production period, at facility one is period 3, and inventory must be carried over to meet the demand in period four. A similar situation arises when inventory is transferred between facility three and facility. Setting the various inventory to zero, thereby introduces a method of controlling the periods in which production takes place.

From Fig. (6.5b), it is obvious that production occurs three times at facility one and twice in both of the other facilities. Incorporating a lead time of one of each facility one to three means that firstly end items will not be available to the end of the time period in which they appear. Secondly facility two items, - in order to be ready for processsing at facility one in the specified time period, - must be processed in an earlier period. Facility's three production must be similarly offset resulting in the following complete production plan.

TABLE (6.5): Results Three Facilities In Series

Time Period	1	2	3	4	5	6
Production Facility 3						
Item 3	**1**	**3**	**0**	**0**	**0**	**0**
Facility 2						
Item 2	**0**	**1**	**3**	**0**	**0**	**0**
Facility 1						
Item 1	**0**	**0**	**1**	**1**	**2**	**0**

Three Facilities General Assembly Structure

This model again consists of three facilities, but instead of arranging the facilities in series they are organized in an assembly format. Two different raw materials are processed at level two, at facility two and three respectively and are then sub-assembled together at facility one. Again the cost structure for each individual facility is defined in the objective function. Cost structures at each facility, and each period vary. (See Appendix).

Four equations are used to define material flow at facility one. Facilites two and three however, both appear at the same level within the product structure and will therefore require three equations each, allowing production in three periods instead of four. Inventory in the final production periods at each facility are constrained to zero. Ensuring anything processed in the final production period, will be procesed at the next facility. The model is represented graphically in Fig. (6.6a), and a network interpretation of the solution is shown in Fig. (6.6b). As explained previously, using a single source network to interpret results, requires additional diagrams for each branch of the product structure. By virtue of possessing two branches, (1,2) and (1,3) this model requires two network diagrams to interpret results.

For reasons explained in (6.4.1), inventory is carried from period 3, facility 1, to meet demand in period four. Owing to the different cost structures, facility two's production pattern and facility three's pattern will differ. Taking production and holding costs into account, all the demand placed on facility two by facility one inthe first period results in minimizing the cost for that facility. Inventory is then carried to meet the demand at the varying production periods facility, ensuring material flow constraints are satisfied at all times. Facility three's cost structure results in the same production pattern as that of facility one, ensuring the items produced at facility one, are produced in the same quantities at facility two, and no items of inventory are carried from a previous period.

Incorporating a lead time of one for each facility, necessitates an expanded planning horizon. Facilities two and three will obviously begin production in the same time period, because they appear at the same level within the product structure. If however the lead time for production at facility two was twice as long as that at facility three production would have to start in an earlier period.

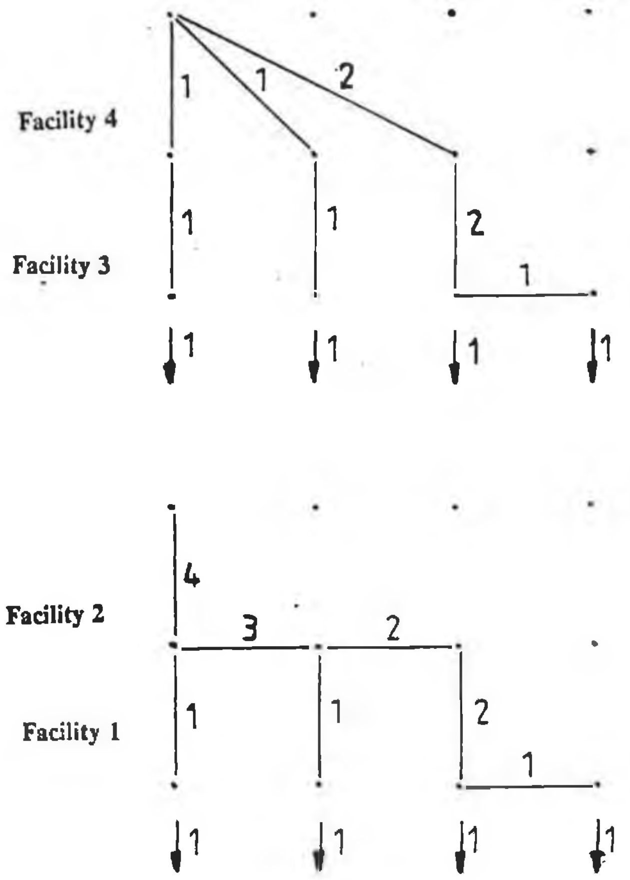
TABLE (6.6): Results Three Facilities; Assembly Structure

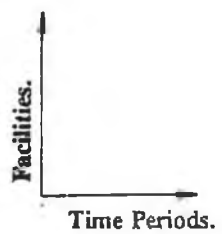
Time Period	1	2	3	4	5	6
Production Facility 3						
Item 3	0	0	1	1	2	0
Facility 2						
Item 2	0	4	0	0	0	0
Facility 1						
Item 1	0	1	1	2	0	0

<u>Two Facilities In Series, - Two Products</u>

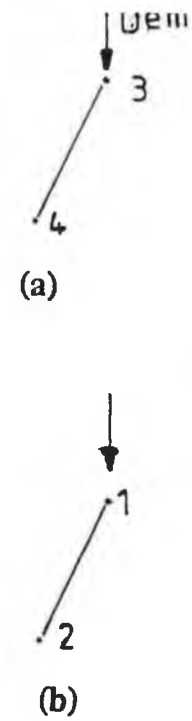
This model demonstrates how the general model can incorporate separate manufacturing processes. The first process consists of two facilities in series, facilities four and three. End items are manufactured at facility three, and so demand at that facility is specified by the market. Raw materials are introduced at facility four. The manufacturing process described by facilities one and two operates in a similar fashion with raw material being introduced at facility two, and end items being completed at facility one.

The cost structure for each individual facility is defined in the objective function (Appexdix 2). In this case facilities one, three and four have the same monotonically decreasing production cost, item four can be produced very cheaply at period one, at facility four, but production in future periods proves expensive.

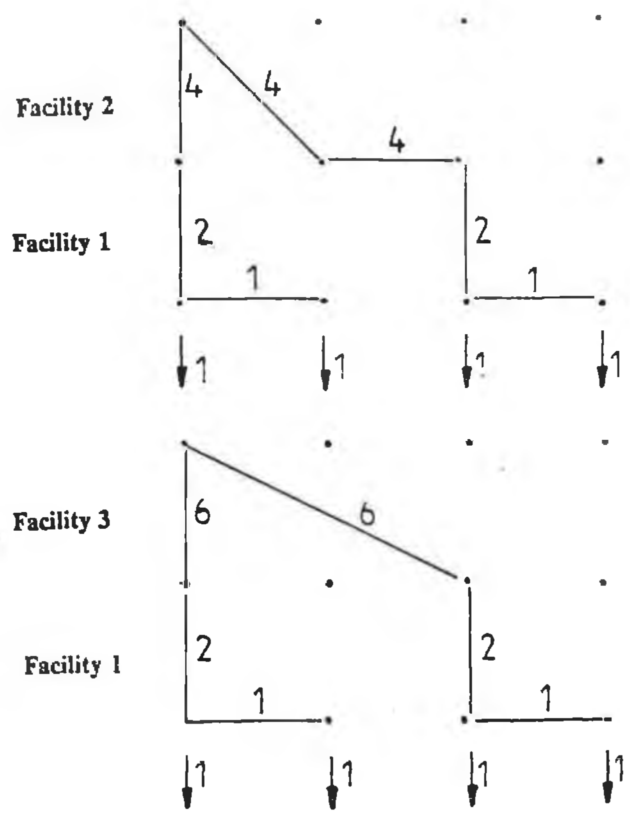


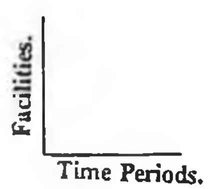


Network Diagram. Fig.(6.7b)

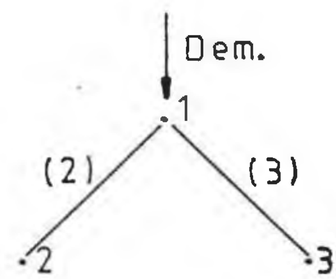


Product Structure. Fig.(6.7a)





Network Diagram Fig.(6.8b)



Product Structure. fig.(6.8a)

Four equations will be required for facilities three and one respectively, because of their appearance at the highest level within the product structure. Items two and four, being produced at the corresponding facilities both also appear on the same level, and so also require a similar number of equations. - Three, one for each period in which production is allowed to occur. The models are represented graphically in Fig. (6.7a) and a network interpretation of the solution shown in Fig. (6.7b).

A separate network diagram is again required for each branch of the product structure, thus necessitating two diagrams. The similar cost patterns introduced in facilities one three and four have resulted in the correspondingly similar production patterns. Item two however is only produed in period one, and is carried to the various periods in which it is required to meet the demand of facility one. Introducing a lead time of one for facility four, and a lead time of two for facility two, results in the corresponding production patterns.

TABLE (6.7): Results Two Products; Two Facilities in Series

Time Period		1	2	3	4	5	6
PRODUCT 1	**Facility 3 Item 3**	0	1	1	2	0	0
	Facility 4 Item 4	1	1	2	0	0	0
PRODUCT 2	**Facility 1 Item 1**	0	0	1	1	2	0
	Facility 2 Item 2	4	0	0	0	0	0

<u>Three Facilities, Varying Quantities Per Parent</u>

In all the models so far described the quantities required per parent item have not been greater than one. This model however is a variation on the three facilities general assembly model, in that items produced at facility two, must be supplied in twos to the sub assembly process at facility one, similarly item one, requires three units of item three produced at facility three. This increase in magnitude of quantity required per parent is easily accomodated within the model, by multiplying the corresponding term in the model by the required factor. Obviously an increase in the number of units produced at each facility will also occur. In the models discussed, market demand has been set at four units divided informly across the planning period, dependant demand at facilities two and three will necessarily increase to eight and twelve respectively.

The cost structure for each individual facility is defined in the objective function (Appendix). Items one can be produced at facility one, very cheaply in periods one and three. Items two can be produced very cheaply in periods one and three. Item three's production costs decrease monotonically across the spectrum of the planning horizon. For reasons explained in previous sections item one's production at facility one is described by four equations, and items two and three are similarly described by three equations. The model is represented graphically in Fig. (6.8a), and a network interpretation of the solution shown in Fig. (6.8b).

The ability to produce cheaply in periods one and three as specified in the objective at facility one, is evident from the network diagram, where all production at that facility is constrained to appear in those periods. Production can take place very cheaply in periods one and two, as demonstrated in the diagram. Total production at this facility equals eight, -twice the production at facility one, and each individual demand placed on facility two by facility one must be met in multiples of two. Similarly, each individual demand placed on facility three by facility one must be met in multiples of three. Item three could be produced more cheaply in period three, however the net effect which would result in changing the overall production plant to accomodate production in this period would not result in a decrease in costs, and therefore is ignored. The offset of production plans at the respective facilities caused by the introduction of lead times at each facility, results in the following production plan.

TABLE (6.8): Results Three Facilities; Varying Quantity Per Parent

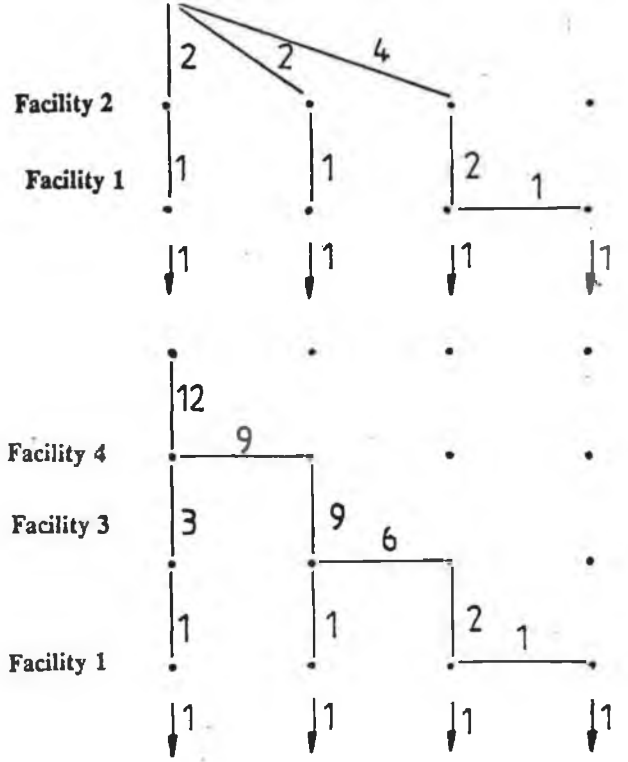
Time Period	1	2	3	4	5	6
Facility One **Item One**	0	0	2	0	2	0
Facility Two **Item Two**	0	4	4	0	0	0
Facility Three **Item Three**	0	6	0	6	0	0

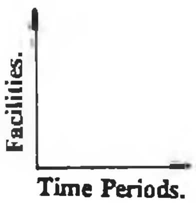
Four Facilities, Varying Quantities Per Parent

This model requires four facilities to complete the manufacture of the product. Raw materials are introduced at facility's two and four and the end item becomes available in facility one. Facility three, which occurs between facility one and four, processes the inventory which arrives from item four, but no sub assembly takes place.

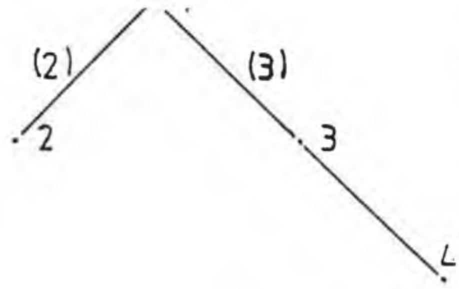
Quantities per parent item greater than one, are included in the model in the same manner as before. The cost structure for each individual facility is defined in the objective function (Appendix). Each facility has the same cost structure, decreasing monotonically over the planning horizon, however, as you go down the product structure the number of periods available in which production can take place will reduce.

Four equations specify facility one's production. Three equations the production at each facility in level two, and two equations,for facility's four production. If the number of levels withing the product structure was to increase past five levels then the span of the planning horizon would have to be extended beyond the new cumulative lead time of the product. The model is represented graphically in Fig. (6.9a) and a network interpretation of the solution shown in Fig. (6.9b). Again because the product structure has two branches, the network diagram falls into two parts.

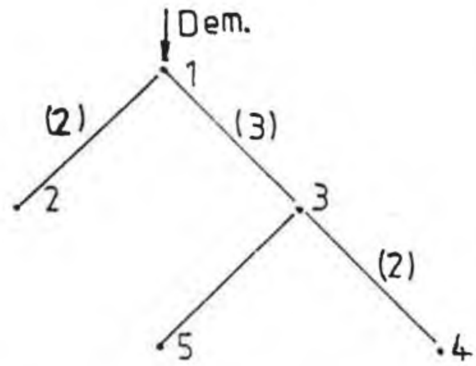




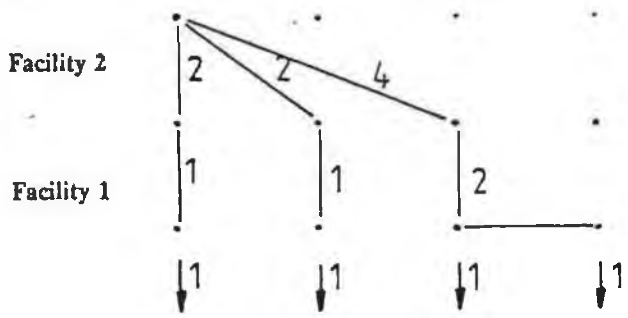
Network Diagram. Fig.(6.9b)

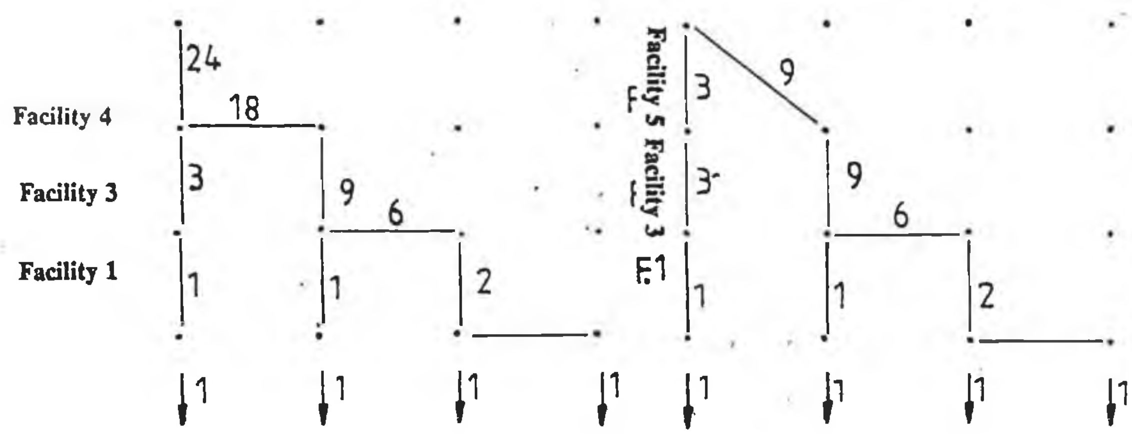


Product Structure. Fig.(6.9



Product Structure. Fig.(6.10





Network Diagram. Fig.(6.10b)

The second half of the network diagram achieves a perfect steps structure, with production taking place in one period at facility four, being spread over two periods at facility three, and advancing to three periods at facility four. The disparity between the timing of production plans, at facility two, and three even though there on the same level, is soley due to an attempt to minimise costs. If it were more economical to spread production at facility three over three periods it would have been done. The inclusion of a lead time of one at each facility results in the following production schedule.

TABLE (6.9): Results Four Facilities; Varying Quantities Per Parent

Time Period	1	2	3	4	5	6	7
Facility One Item One	0	0	1	1	2	0	0
Facility Two Item Two	0	2	2	4	0	0	0
Facility Three Item Three	0	3	9	0	0	0	0
Facility Four Item Four	12	0	0	0	0	0	0

<u>Five Facilities. Varying Quantities Per Parent</u>

This model consists of five facilities, arranged on three levels. Facility one assembles, end-item, from input from facilitys two and three. Facility two processes raw material, and facility three performs a subassembly on processed raw material from facilitys' four and five. The quantity required per parent varys from facility to facility.

The cost structure for each individual facility is defined in the objective function.

Cost structures at each facility are similar, but, planning horizon spans, will vary from level to level, as in previous models. (See Appendix).

Four equations are again used to define material flow, at facility one. Facilities which are used in manufacture of the product at level 2 of the product structure, will only manufacture in three periods and therefore only three equations are required to describe material flow at facilities two and three. Similarly only two equations are required to describe material flow at facilities occuring within level three of the product structure.

The model is represented graphically in Fig. (6.10a) and a network interpretation of the solution is shown in Fig. (6.10b). The associated network diagrams can be explained in similar way to the other models. These results are listed in Table (6.10) using a lead time of one period for level two items, and two for level three items.

TABLE (6.10): Results Five Facilities; General Assembly Structure

Time Period	1	2	3	4	5	6	7
Facility One **Item One**	0	0	0	1	1	2	0
Facility Two **Item Two**	0	0	2	2	4	0	0
Facility Three **Item Three**	0	0	3	9	0	0	0
Facility Four **Item Four**	24	0	0	0	0	0	0
Facility Five **Item Five**	3	9	0	0	0	0	0

6.4.9 Limitations Placed On Model By Linprg2 Package

The Linprg2 package, used for the previous worked examples, is a very small package, used only for demonstration and testing. The maximum number of constraints that may be imposed is twenty and the total number of elements present in the objective function may not exceed thirty.

Before examining the relationship between items, levels and planning horizon, it must be pointed out, that, the minimum planning horizon required is independant of the number of items within the product structure, but is dependant upon the number of levels.

For a planning horizon of four periods and a manufacturing concern, with all facilities arranged in series, Fig. (6.11), the no. of constraint equations generated is

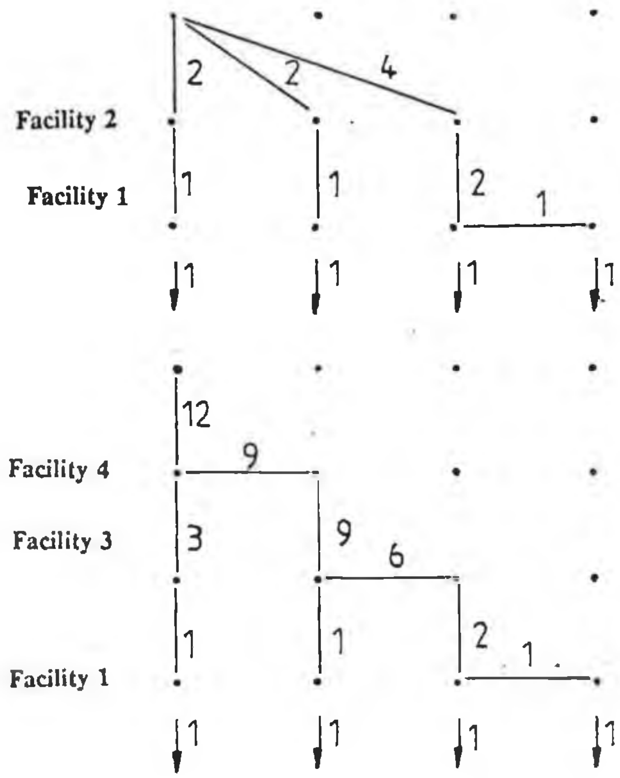
$$4 + 3 + 2 + 1 = 10$$

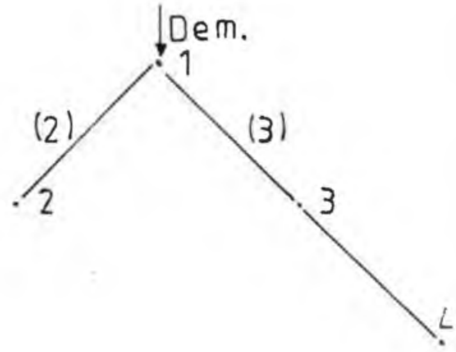
At levels to 0-3 respectively. This means however that 10 of the 20 possible constraints have not been used up, and only twenty elements appear in the objective function. If one item, (also with a lead time of one) is added to the product structure at level two and another at level three the number of constraint equations increases to:

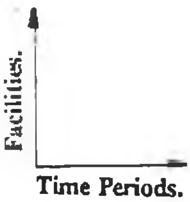
$$4 + 3 + 2 + 2 + 1 + 1 = 13,$$

And objective function elements to 26. Tables (6.11 - 6.13) describe the relationship between items, levels and planning horizon, keeping in mind the constraints of the Linprg2 package.

When an item is added to a product in an already existing level, the cumulative lead time, will not change, and so neither therefore will the minimum planning horizon, the minimum number of equations therefore, will only increase by a magnitude equal to the cumulative lead time less the level to which the item has been added. The maximum planning horizon, determines the number of equations which will be generated and is therefore determined by the package size, which sets a limit on the number of equations generated. As items within the product structure increase, the

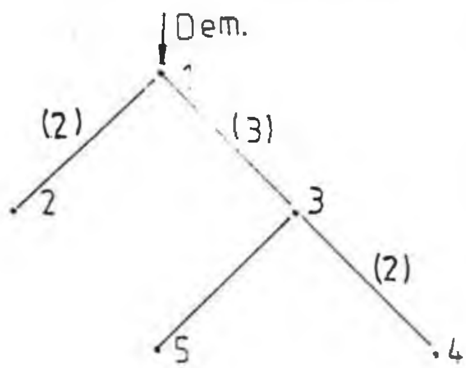




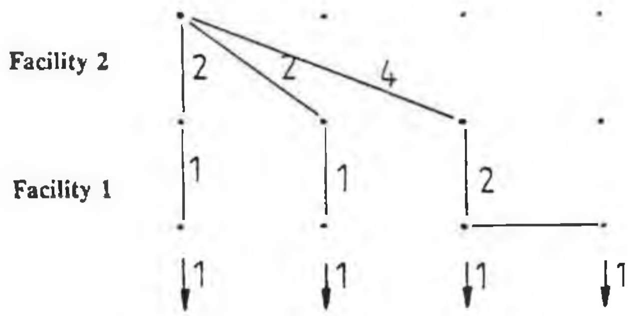


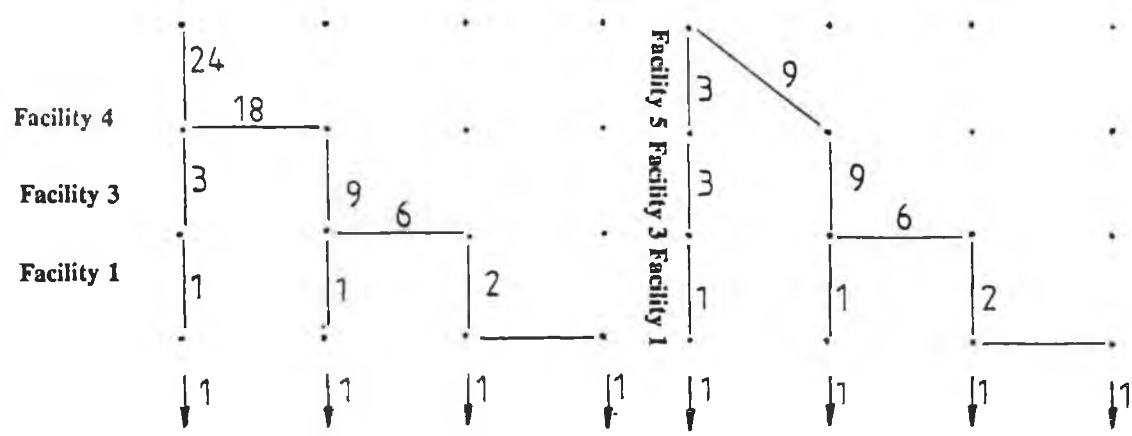
Network Diagram. Fig.(6.9b)

Product Structure. Fig.(6.9



Product Structure. Fig.(6.10





Network Diagram. Fig.(6.10b)

TABLE (6.11): Increasing Items, (Within Levels)

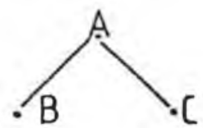
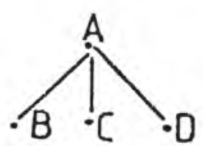
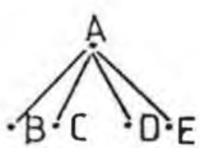
Product Structure	Number of Items	Cumulative Lead Time	Planning Horizon	Levels	Number of Equations	No. Terms in OBJ F
	3	2	Min 2 Max 5	2	Min 4 Max 13	Min 8 Max 26
	4	2	Min 2 Max 4	2	Min 5 Max 13	Min 8 Max 26
	5	2	Min 2 Max 3	2	Min 6 Max 11	Max 12 Max 26

TABLE (6.12): Increasing Items, (And Levels)

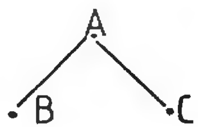
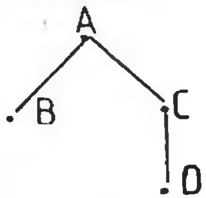
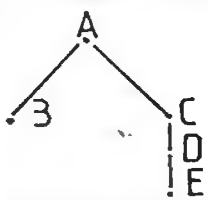
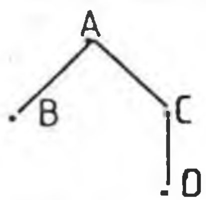
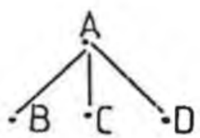
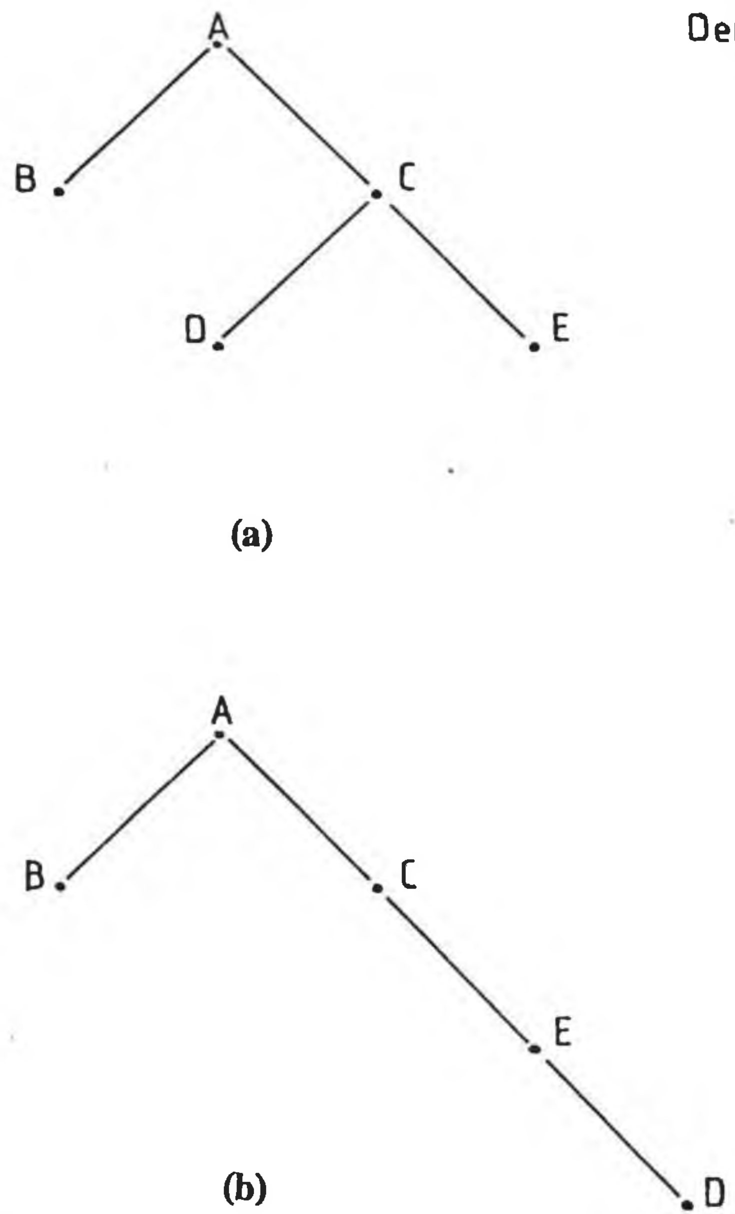
Product Structure	Number of Items	Cumulative Lead Time	Planning Horizon	Levels	Number of Equations	No. Terms in OBJ F
	3	2	Min 2 Max 5	2	Min 4 Max 13	Min 8 Max 26
	4	3	Min 3 Max 4	3	Min 8 Max 12	Min 16 Max 24
	5	4	Min 4 Max 4	4	Min 13 Max 13	Max 13 Max 13

TABLE (6.13): Increasing Levels Only

Product Structure	Number of Items	Cumulative Lead Time	Planning Horizon	Levels	Number of Equations	No. Terms in OBJ F
D C B A	4	4	Min 4 Max 4	4	Min 10 Max 10	Min 20 Max 20
	4	3	Min 3 Max 4	3	Min 8 Max 12	Min 16 Max 24
	4	2	Min 2 Max 4	2	Min 5 Max 13	Max 10 Max 26

Product Structures.

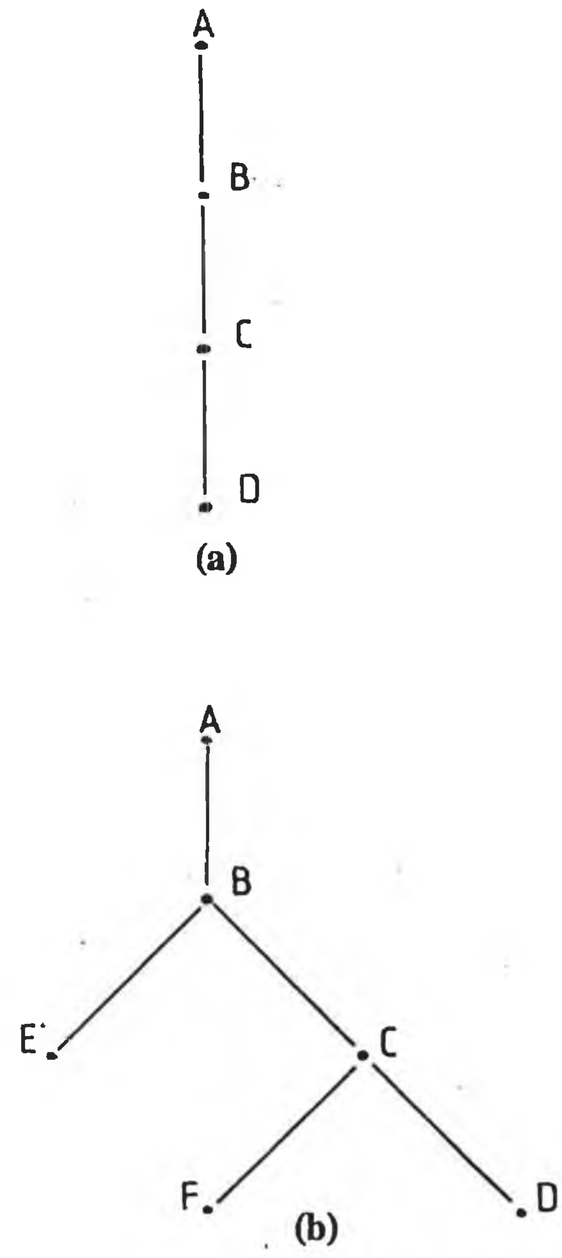


Demand Level.

Level 1

Level 2

Level 3



Fig(6.12) Product Structure. Fig(6.11)

number of equations will increase, but the increase is determined, by the planning horizon length, and also, the items position with the structure, Table (6.11).

When both the item and levels are increased simultaneously the cumulative lead time must also increase, which means that the minimum planning horizon will also increase. The maximum planning horizon will again eventually start to reduce, by virtue of the constraint placed upon it by package size. The number of equations generated, is dependant upon both the planning horizon length, and the distribution of items, for example, moving an item from level to the next lower level reduces the number of equations by one. Fig. (6.12) for planning horizon of four, has

$$4 + 3 + 3 + 2 + 2 = 14$$

Whereas Fig. (6.12b) generates

$$4 + 3 + 3 + 2 + 1 = 13$$

The planning horizon, always sets the starting number of equations, ie. at level 0, and the number of equations at the other levels are determined accordingly. As the number of items increase, the maximum cumulative lead time (CLT) will increase, but, the minimum CLT will remain constant.

The relationship between items/levels/time periods, is ultimately a very simple one. The number of items, which can be added to product structure, is determined by the rate of convergence of the minimum to maximum planning horizons. By adding items to the product structure within levels, with maximum planning horizon reduces, converging towards the minimum planning horizon. When adding items to a product structure and generating the item on a new level, both the minimum planning horizon increase, and the maximum reduces. When the maximum planning horizon is equivalent to the minimum value no more items may be added to the product structure, unles the package capacity is increased. This will happen at a much slower rate however when the items are added, to an existing level.

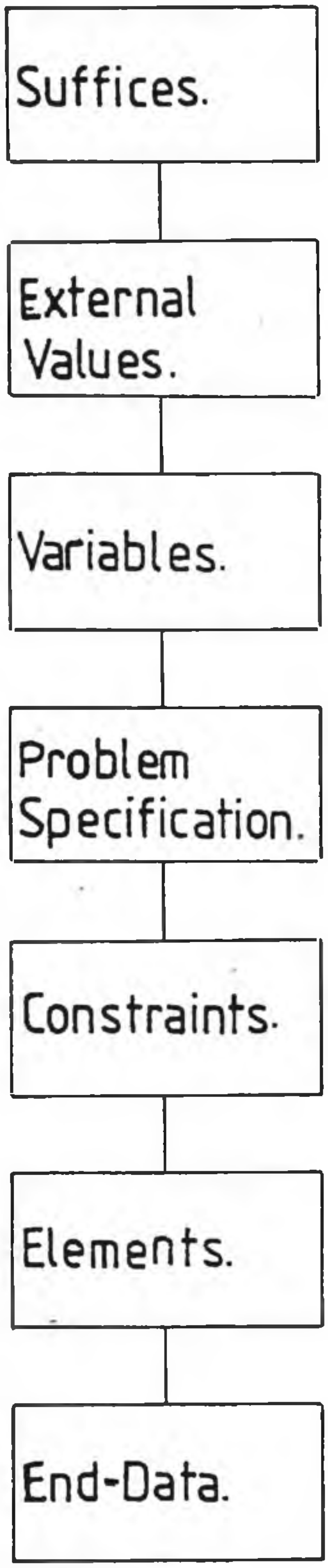
6.5 THE SCICONIC AND MGG PACKAGES

6.5.1 Explanation Of Relationship Between Input To Both Packages

The package used to investigate the examples in section 4.6 places limitations on the size of the model (See Section 4.7.1). It was therefore decided that to test the model performance under various operating conditions, a more advanced programming package would be used. The best available package was SCICONIC, operating on the University main frame, using a matrix generator to formulate the problem file.

Using the Linprg2 package, the model, was submitted (in equation form) in a data file directly to the package (Appendix 2). Larger mathematical programming packages used for problem solving throughout industry operate using input presented in what is referred to as a standard matrix format. The formulation of this standard matrix format is done by specifying, pertient data, in program form (Appendix 3a). This data consists of any subscripts, external valve names, or equations used in the model formulation. Actual data required by the model, (ie. holding/production costs) are supplied in a separate data file (Appendix 3b) in a format specified by a spin off file generated by this program. Once this has been created, the standard matrix format can be generated (Appendix 3c).

In the model formulation file, each equation is given a name, whether it be the objective function or a material balance constraint. The matrix file consists of three sections. The first section lists the name of each individual equation. In order to identify the various equations more easily. The objective function was named "cost". Equation introducing capacity "CAP" with a number specifying facility, and any material balance equations "MATB" proceeded by two numbers, one signifying facility and a second the period in which it occurs. MATBB14, is therefore concerned with material flow at facility one and period four.



Suffices. Defines Facilities(i), Periods(t).

External Values. Defines Costs(C,H), Demand(D), in terms of Suffices.

Variables. Defines Variables(P,I) in Terms of Suffices.

Problem Specification. Defines Objective Function.

Constraints. Specifies Material Balance Constraints in terms of Variables and Elements.

Elements. Defines and abbreviates Numerical Values in Alphabetical Form,

End-Data. Signals end of Program.

Summary of Program File Sections. Fig.(6.13).

The second section consists of variable names, equation names and integers. Each variable is listed once, and adjacent to it is the name of the equation it appears in, and the associated integer value (multiple) it take on, in that equation. By listing each variable and associated integer it is possible to compile the left hand side of any equation, for example.

$$\text{MATB21:} \; -1(\text{IN21}) + 1\,(\text{PR21}) -1\,(\text{PR11}) = 0 \qquad (6.30)$$

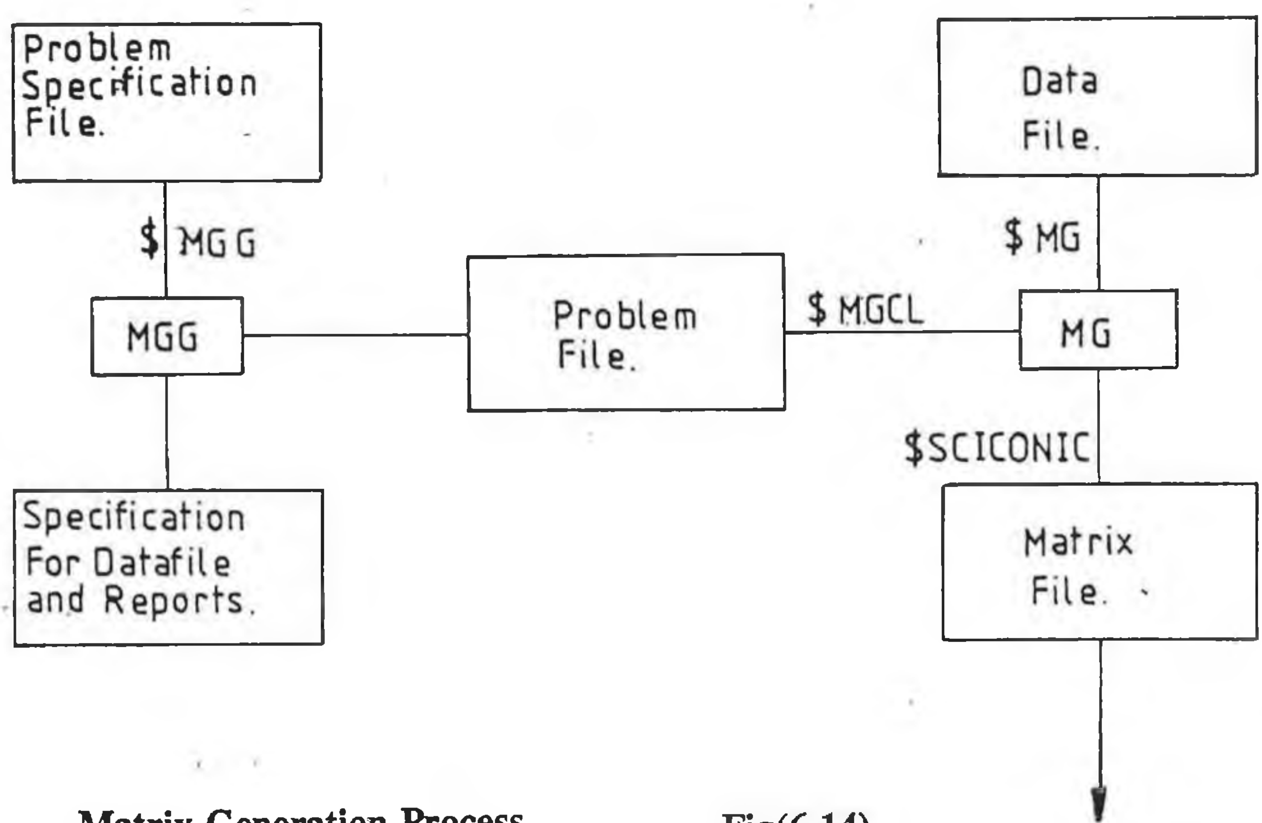
The right hand side of the equation is zero, because section three only lists those equations whose right hand sides have a value other than zero.

The above equation is comparable to any found as input to Linprg2 in Appendix (2). The output from the sciconic package is Appendix (3d) is different to that of the Linprg2 package. Output in the case consists of three sections. The first gives data regarding number of iterations required, to arrive at the optimal solution, and the name and valve of the objective function. The second section lists the various equation names, and the corresponding righ hand side values. The upper and lower bounds are also listed. These will vary only when branch and bound is used. Section three lists all the variables used, and the valves they obtain in the optimal solution input costs, - production and holding costs are also listed for each variable.

6.5.2 SCICONIC And Matrix Generation

Mathematical programming techniques are used in a wide variety of areas to generate optimal solutions to problems. In order to solve the problem, the problem must be formulated in a way that can be universally understood. This format is referred to as a standard matrix (MPS) format. In order to generate this standard matrix format one of two appraches may be adopted,

1. Write the matrix generater in standard programming language, ie fortran.



Matrix Generation Process. **Fig(6.14)**

2. Write the matrix generater program in a specialized high level language.

MGG (Matrix generator, generator), is a high level mathematical programming language which combines the advantages of both approaches.

6.5.3 Formulation

A formulation is shown in Appendix (3a). The formulation consists of many sections, namely:

1. Subscripts
2. External Values
3. Variables
4. Problem Specification
5. Constraints
6. Elements
7. End.

The subscripts section is used to define, the various suffices used in the model and their respective maximum values. The external values, is used to name, the various constraints required in the model which must be read in from a data file. The variables section, is used to define the variables, which must be calculated by the program. The objective function, is defined in the problem section, in terms of the variables and constants which have been defined. The constraints section, defines the various constraints required. Notice that all the constraints must be named with respect to the suffices used in the program. The elements section, is just used to define any of the constraints, which have been given names interval to the generator, generator file, such as the RHS of constraint equations.

6.5.4 Running The Matrix Generator Generator (MGG)

Once the matrix generator has been produced, running MGG produces the following files:

1. MGGOP. LIS
2. GLOBAL. FOR

3. INPUT. FOR
4. MG. FOR
5. MG. COMS
6. RW. FOR
7. RW. COMS

The MGGOP. LIS files, lists the errors and warning which have been identified, together with the place in which they occur. And the MG. FOR is a FORTRAN version of the generator, generator file. The global file, is empty, unless a functions section has been defined in the generator file. If this is the case then this file, contains the FORTRAN functions. The other files are not of any interest to the user, specifying the format of the output etc.

6.5.6 Running MGCL

Running MGcl, compiles and links the various files, to the MGG object library, to produce the complete MG program.

6.5.6 Running MG

MG must be run, with the data file (Appendix 3b) containing the various constraints required by the model as input. The format for this data file is found in the MGGOP.LIS list file. Any errors found in the data file format are listed in the MGOP list file. The standard matrix (Appendix 3c) format, (MPS) of the model, is listed in matrix data file. It is this file which act as input to sciconic, - to solve the model presented.

6.5.6 Running SCICONIC

The commands necessary to run SCICONIC are shown in Fig. (6.16). The output is shown in (Appendix 3d). The values of the various variables are listed in the activity column.

6.6 RESULTS SECTION

6.6.1 Results Using SCICONIC Integer Programming Package

The flexibility of the sciconic package, allowed a great deal of investigation into the programming efficiency and performance of the model under a variety of operating conditions.

The first test carried out was done so, in order that the effect (if any) a change in either product structure, cost structure or demand function may have on the number of iterations (and hence solution time) for product structures with varying numbers of levels and facilities. A planning horizon of six time periods is used. A total of 9 different product structures spanning two to five levels are examined for a variation in iterations required to find the optimal solution, under seven different operating conditions. These conditions are as follows:

A. Cost structure is the same at all facilities.
B. Cost structure is varied at each facility.
C. The demand function is varied at each.
D. A different variation in demand is used.
E. The number of facilities per level is varied.
F. Quantities required per parent facility are increased above 1.
G. Using product structures specified in F, cost structues are set at the same level at each facility.

The following table, shows the trend in iterations which accompany these varying conditions.

TABLE (6.14): Trend in Iterations for Various Conditions.

No. of Levels	No. of Facilities	No. of Iterations Per Operating Conditions A	B	C	D	E	F	G
2	2	12	15	15	15	X	15	18
2	3	18	23	23	23	X	24	24
3	4	24	33	33	33	33	31	30
3	5	30	41	41	41	41	44	36
4	6	36	51	51	51	51	46	42
4	7	42	61	61	61	61	50	48
5	8	48	71	71	71	71	52	54
5	9	54	81	81	81	81	70	60
5	10	60	91	91	91	91	73	66

The table (6.14) shows that as the size of the product structure increases, both in terms of facilities and levels, the number of iterations increase. Under conditions of uniform demand, with the cost structure at each facility being identical, the addition of further facilities causes an increase of six iterations, in determining the optimal solution. It is interesting to note that this increase is independent of where in the product structure the facility is placed - within an existing level, or creating a new one.

When the cost structure across the planning horizon is varied at each facility, the number of iterations associated with each product structure increase slightly from the previous value. Product structures of greater than three levels, experience an increase of four iterations per facility. Those product structures of less than three levels have a smaller increase.

Keeping the same cost structures the various product structures performances are also investigated, using two different lumpy demand structures. Changing the demand patterns had no effect whats so ever on the number of iterations necessary.

Operating condition E, keeps the previous demand and cost structures, but again varies the product structure slightly to ensure the consistency of the results. No change occurs in the iteration numbers. The top two product structures in the table cannot be changed and so this column is left blank in the table.

All product structures used in previous operating conditions, did not contain quantities per parent items greater than one. Option F however introduces varying quantities. The demand pattern for this test was uniform. Comparing the interations required here with those of test A (uniform cost structures and quantity per parent equal to one), each product structure requires a slightly higher number of iterations than its test A counterpart. As the no of facilities increase, this number of iterations also increases. No direct relationship between facilities and iterations can be found, in this case. (Uniform demand, varying cost structure, quantities per parent greater than one).

Test G, retains both the same product structure and demand function as test F, but this time cost structures are made uniform at each facility. Comparing these results to test A results, the number of iterations required for the smallest product structures is six higher than that required for Test A, and this difference is maintained as your advance down through the product structres. Another interesting point to note is the number of iterations is independent of the exact quantity per parent dependant only on the fact that the quantity is greater than one. The table demonstrates that test G'S results are similar as those incurrred by product structures less one facility under Test A conditions.

Conclusions

1. Under steady state conditions (uniform cost structure, demand pattern, quantity per parent equal to one). The number of iterations required to find the optimal solution is independent of where in the product structure a new facility is applied.
2. A change in cost structures or demand pattern or both, increases the number of iterations to a higher but constant level.
3. The number of iterations required caused by a change in product structure by increasing the quantities required per parent, is affected by demand patterns (unlike the case where quantities per parent equal one). These iterations while obviously increasing as facilities increase would appear to depend on both demand pattern and cost structure.

6.6.2 Implications of Dynamic Planning Horizon

The previous tests in section 6.6.1 were carried out, without the use of dynamic planning horizons, within the product structure (i.e. planning horizon varying as you advance down through the levels). Tables (6.15 a,b,c,d) show the percentage reduction in solution variables you would expect, by the introduction of the dynamic planning assuming planning horizon spans of 6,8,10, and 12, and a maximum of 6 items and 6 levels. The number of items cannot be greater than the number of levels, and so the upper half of each table above the diagonal must remain blank.

The number of possible solution variables is dependent upon the arrangement of facilities within the product structure. (Assuming a dynamic horizon). The more levels within the structure the smaller the number of solution variables, (see section 6.4.7) and therefore the greater the percentage decrease from the number required using static planning horizons.

The results in Tables (6.15. a,b,c,d) make two necessary assumptions.

1. Lead time at each facility is one.
2. Product structures are arranged so that the greatest percentage reduction occurs.

Development of Tables

All percentages are arrived at in the following manner. For each facility in each planning horizon two solution variables exist, P_{it}, I_{it}. Assuming a static planning horizon the total number of solution variables

2 x Number of Facilities (N) x Number of Periods in planning horizon (T).

The model says

$$T = R_i \text{ (End Item)}$$

$$R_i = R_{p(i)} - L_{p(i)} \text{ For all Components.}$$

where R_i : planning Horizon Length; $L_{p(i)}$: lead time of Parent;

J : Number of Levels; N_j : No. of Facilities at each Level.

and

$$P_{it} = 0 \qquad t > R_i \text{ all i}$$

$$I_{it} = 0 \; t \geq R_i \text{ all i}$$

For a product structure with J levels

TABLE (6.16): Terms Required For Reducing The Number of Variables.

Lvls.	Planning Horizon Length	Number of P_{it} Variables	Number of I_{it} Variables	N_j
1	T	T - T	T - T + 1	N_1
2	$T-\sum_{j=1} L$	$T-(T-\sum_{j=1} L_{j(i)})$	$T-(T-\sum_{j=1} L_{p(i)})+1$	N_2
3	$T-\sum_{j=2} L$	$T-(T-\sum_{j=2} L_{p(i)})$	$T-(T-\sum_{j=1} L_{p(i)})+1$	N_3
J	$T-\sum_{j=J-1}^{1}$	$T-(T-\sum_{j=J-1} L_{p(i)})$	$T-(T-\sum_{j=J-1} L_{p(i)})+1$	N_j

Table(6.16) Develops the Various terms which are required to generate the number of terms which must be set to zero when using the Dynamic Planning Horizon. For each level within the planning horizon account must be taken of Production and Inventory Variables at each facility.

$$\sum_{j=1}^{J} N_j[(T - (T-\sum_{j=J}^{1} L_{p(i)}) + (T - (T-\sum_{j=J}^{1} L_{p(i)}) + 1))] \quad \textbf{(6.31)}$$

$$\sum_{j=1}^{J} [\sum_{j=J}^{1} L_{p(i)} + \sum_{j=J}^{1} L_{p(i)} + 1] \quad \textbf{(6.32)}$$

$$\sum_{j=1}^{J} N_j \; [2 \sum_{j=1}^{J} L_{p(i)} + 1] \quad \textbf{(6.33)}$$

The term $\Sigma L_{p(i)}$ is the lead time so far accumulated within the product structure-the sum of the lead times for the parent items at this level.At level Three for example this term would be accumulate lead times over levels' one and two. For the purposes of these tests the lead time at each facility was assumed to be one and two respectively.The sum of accumulated lead times can therefore be equated to the number of levels.

$$\sum_{j=J-1}^{1} L_{p(i)} = J-1 \quad \textbf{(6.34)}$$

The equation then becomes:

$$\sum_{j=1}^{J} [2(J-1)] \quad \textbf{(6.35)}$$

Eqn.(6.35) describes the number of variables to be set to zero within each product structure. The percentage decrease in variables due to the use of the dynamic horizon can now be easily calculated.

Discussion of Tables

Comparing the four tables (6.15 a,b,c,d) it is obvious that all four have similar trends, increasing both as you go down the table in the direction of increasing facilities and also as you go across the tables in the direction of incresing levels. The magnitudes of these increases however vary both within the table itself and between tables.

A product structure containing six levels, and a lead time of one at each level must have a minimum planning horizon span of six periods, if end item production is to take place. Table (6.15a), therefore it is calculated over six periods. Adding items within the levels results in percentage decreases, which increase as the number of items increase. The increment of the increase which results as each item is added however reduces as the number of items added increases. As the planning horizon extemps, the number of items which can be added to the product structure in order that a comparable reduction in number of variables is achieved due to the utilization of dynamic horizon is increased far beyond the number required at smaller planning horizons.

As product structures develop from general assembly structures to series structures, the decrease in the number of solution variables also increases. As more and more items are removed from inner levels in order to add extra levels to the product structure, this percentage decrease, increases. This increase however reduces as you advance across the table. For a general assembly structure removing the first item from an inner level, will have greater effect on the overall efficiency of the model than removing the last possible item. As the number of items within the product structure increase, the magnitudes of the increases, in percentage decrease are getting larger.

Imagine two product structures, one with 5 items and the other with six items both with two levels removing an item from an inner level in the former model and creating a new level within the product structure will cause a smaller increase in

TABLE (6.15b): Percentage Decrease in No. of Solution Variables With Planning Horizon (Dynamic)

Level / Item	2	3	4	5	6
2	9%				
3	12%	17%			
4	14%	20%	23%		
5	15%	22%	27%	30%	
6	16%	24%	30%	34%	36%

(best case always taken - majority items on last level)

(Planning Horizon = 8)

TABLE (6.15a): Percentage Decrease in No. of Solution Variables With Planning Horizon (Dynamic)

Level / Item	2	3	4	5	6
2	13%				
3	17%	22%			
4	19%	27%	31%		
5	20%	31%	36%	40%	
6	21%	32%	40%	46%	49%

(best case always taken - majority items on last level)

(Planning Horizon = 6)

TABLE (6.15c): Percentage Decrease in No. of Solution Variables With Planning Horizon (Dynamic)

Level Item	2	3	4	5	6
2	7%				
3	10%	13%			
4	11%	16%	19%		
5	12%	18%	22%	24%	
6	13%	19%	24%	28%	29%

(best case always taken - ie give greatest decrease)

(Planning Horizon = 10)

TABLE (6.15d): Percentage Decrease in No. of Solution Variables With Planning Horizon (Dynamic)

Level Item	2	3	4	5	6
2	6%				
3	8%	11%			
4	9%	14%	16%		
5	10%	15%	18%	20%	
6	10%	16%	20%	23%	24%

(Planning Horizon = 12)

percentage decrease than if the same were done in the six item model. However, as both models come closer to achieving serialisation ie. one item one level this increase, in the percentage decrease, although higher in the product structure with the greater number of items, converges to approximately the same number.

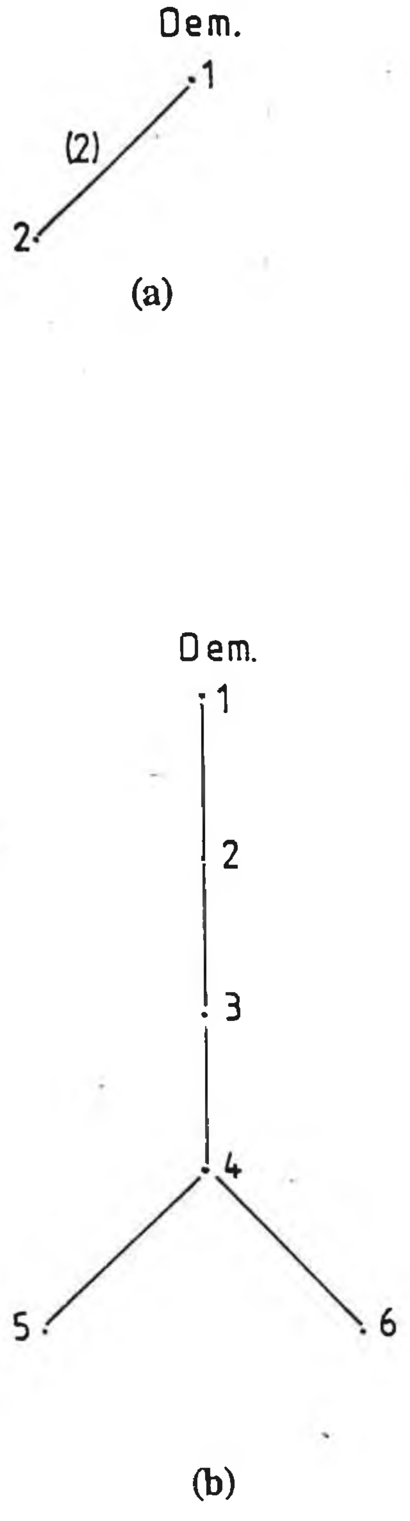
As the planning horizon increases percentage decreases in the number of variables decrease (due to an increase in the number of variables, before the dynamic horizon is introduced). As the planning horizon lengthens however, the number of items which must be added to the product structure in order than greater utilization of the dynamic horizon is made is increased. The range of the increases incurred, by increasing levels within the product structures also decrease as the planning horizon advances.

Test Of Table Predictions

In order to test the predictions of Tables (6.15 a,b,c,d) the solution times of two product structures were investigated. These product structures are shown in Fig. (6.16). Tests were carried out in order to find the average solution solution times for the two product structures, using planning horizon lengths, which varied from 2 to 12. The product structures were investigated firstly using no dynamic horizon, Tables (6.18 a,b) and secondly with a dynamic horizon Tables (6.19 a,b). For each product structure, increasing the length of the horizon resulted in an increase in solution time. (See Appendix (7) for these results).

Comparing the practically obtained results for both product structures, in terms of percentage decrease in solution due to a decrease in the number of solution variables, with Tables, (6.15 a,b,c,d) the results obtained are very similar. Table (6.17) compares the results.

Both models were investigated under conditions of varying demand, different cost structures per period and differing quantities per parent items.



Product Structure. Fig.(6.16).

Table (6.17) shows that practical results are within $\pm$ 5% of theoretically obtained percentage reductions due to the dynamic planning horizon.

TABLE (6.17): Comparison of Practical, Theoretical Effect of Dynamic Horizon.

	Planning Horizon Length.	6	8	10	12
Product Structure Fig. 1	Practical	13%	9%	7%	6%
	Theoretical	13%	10%	6%	9%
Product Structure Fig. 2	Practical	46%	34%	23%	28%
	Theoretical	40%	34%	27%	23%

Conclusions

Product structures, with, small numbers of both items and levels, can obtain greater benefits from the dynamic horizon, using a shorter horizon span. As the product structure becomes more serialized (assuming const number of items) (ie. spread over a greater number of levels) the dynamic horizon achieves greater benefits.

As the planning horizon lengthens, the size of the product structure required to achieve comparable reductions in the number of variables increases. An increas in the number of levels in the product structure causes these benefits to be achieved to much greater magnitude.

Irrespective of planning horizon length, complex product structures, with many items and levels, may use the dynamic planning horizon to great effect, the greater the number of levels within the structure the greater the effect.

6.6.3 Comparison of the Various Lot Sizing Methods

Introduction

The various lot sizing methods currently in use today, are discussed in section 6.2,

6.6.3 Comparison of the Various Lot Sizing Methods

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The various lot sizing methods currently in use today, are discussed in section 6.2, and their respective advantages/disadvantages in Table (6.24). This section seeks to show the disparity between the requirements planned using these techniques, and those obtained using a linear programming formulation. Many manufacturers favour a Lot-For-Lot Method of lot sizing but this also has inherent problems. Four methods are chosen from among those discussed each representing a particular type of lot sizing procedure.

Wagner Whitin is chosen to represent the dynamic approach to lot sizing, economic order quantity the static approach, and period order quantity a slight mixture, where the timing of orders is the same, but the amount ordered varies. Finally the Lot-For-Lot method is also included. (As with all other methods, the planned quantity is rounded to the nearest whole number). Both the economic order quantity and period order quantity, can not accommodate changing costs per period, and so an average cost per period is used for comparative purposes.

A three facility model is used to compare the methods, and the respective cost structures are shown in Table (6.21a). Each model is tested over five different demand patterns. It must be mentioned however, that the quantities required per parent items are both equal to one, which means that the results obtained with Wagner Whitin, Economic order quantity and period order quantity methods, applied independently at each level, are better than would usually be expected, if this number were greater than one in comparison to the linear programming and Lot-For-Lot solution. The demand patterns are listed in Table (6.21b). They are lumpy, uniform, convex, increasing and decreasing.

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TABLE (6.21b): The Various Demand Patterns Test ed.

Period	1	2	3	4	5	6
Dem 1	6	0	7	2	8	1
Dem 2	4	4	4	4	4	4
Dem 3	2	4	6	6	4	2
Dem 4	1	2	3	5	6	7
Dem 5	7	6	5	3	2	1

TABLE (6.21a): COST STRUCTURE

Costs \ Time Period		1	2	3	4	5	6	AV COST/PER
ITEM 1	P COSTS	10	5	10	5	10	5	7.5
	H COSTS	1	1	1	1	1	1	1
ITEM2	P COSTS	10	5	1	1	5	10	5.3
	H COST	1	1	1	1	1	1	1
ITEM 3	P COSTS	1	5	10	10	5	1	5.3
	H COSTS	1	1	1	1	1	1	1

P COSTS: Production Costs

H COSTS: Holding Costs

Inventory holding costs are calculated on the basis of average inventory, in a period, with inventory at the beginning and at the end of a period being taken for the average calculations. Production costs for the Lot-For-Lot, Wagner Whitin and linear programming solutions are based on the cost in which the requirement arises. Economic order quantity and period order quantity production costs are based on the average cost per period.

Once the total costs for each of the methods performance over the various demand patterns was ascertained, a cost index was used to allow easy comparison of their relative performance. For each demand pattern, the performances of the various techniques were compared to the performance of the linear programming solution. The following cost index was used.

$$\text{COST INDEX} = \frac{\text{Techniques Total Cost}}{\text{Linear Programs Total Cost}} \times 100$$

Table (6.22) lists the results obtained and the Lot-For-Lot method performs consistently better than either of the other three methods, over all the demand pattern. The period order quantity method also performs better than either of the other two methods when dealing with all but the convex demand pattern. Wagner-Whitin performs better than the economic order quantity method, on all but one occasion. It may therefore be said that of all the methods the economic order quantity method, produces results which are the farthest removed from the linear programming method.

Table (6.23) ranks each of the methods in order of decreasing efficiency, based on a scoring method, which gives one to four marks for coming first to fourth respectively.

TABLE (6.23): Average Scores

METHOD	AVERAGE SCORE
Linear Programming	----
Lot-For-Lot	1.0
Period Order Quantity	2.2
Wagner Whitin	3.0
Economic Order Quantity	3.8

The period order quantity method would appear from Table (6.23) to have slightly more difficulty dealing with the convex demand patterns than with any of the other demand patterns. Alternatively Wagner Whitin would appear to have coped best with the convex demand pattern. Wagner Whitin did least will in coping with the decreasing demand pattern. The economic order quantity would appear to have coped best with this demand pattern, but produced the worst costs when dealing with the other four demand patterns.

Examining each method individually for the variation in costs which each demand pattern brings about, it is interesting to see that, the cost variation enjoyed by Wagner Whitin, is approximately 28%, which may be attributed to the difference in production costs incurred by the increasing and decreasing demand patterns. The linear programming solution attains the next highest variation in costs, ~ 20% variation, due this time to the lumpy demand pattern, which incurred large production costs in comparison to the increasing demand pattern. A 10% variation in cost was calculated for the Lot-For-Lot method. The reason for this was again due to the lumpy versus increasing demand patterns. The lumpy demand pattern was found to be the most difficult to deal with, and production costs accumulated were quite large. Period order quantity method, resulted in only 5.6 percentage variation, this variation is due to the variation in holding costs between the lumpy and convex demand patterns. This method incurred lower holding costs when dealing with the lumpy demand pattern, than with the convex pattern. The economic order quantity, which performs the worst overall of all five methods, produces a small variation in costs, -

6.7%. The reason for this variation is similar to that of the Wagner Whitin method, increasing and decreasing demand patterns, but in this case it is the holding costs which cause the variation, being slightly higher using the increasing demand pattern, than the decreasing pattern. The production costs incurred by the linear programming solution are lower than those incurred by all other Lot-Sizing methods, for each and every demand pattern.

The holding costs however incurred by the Lot-For-Lot method of ordering will obviously be lower. This method is the only method which results in consistently lower holding costs across the spectrum of demand patterns. Wagner Whitin has lower holding costs, with the convex and increasing demand patterns and period order quantity, using lumpy and increasing demand patterns.

The holding cost reduction however, which would be achieved by using any of these methods, is more than compensated for by the opportunity cost, in production terms of retaining the linear programming method.

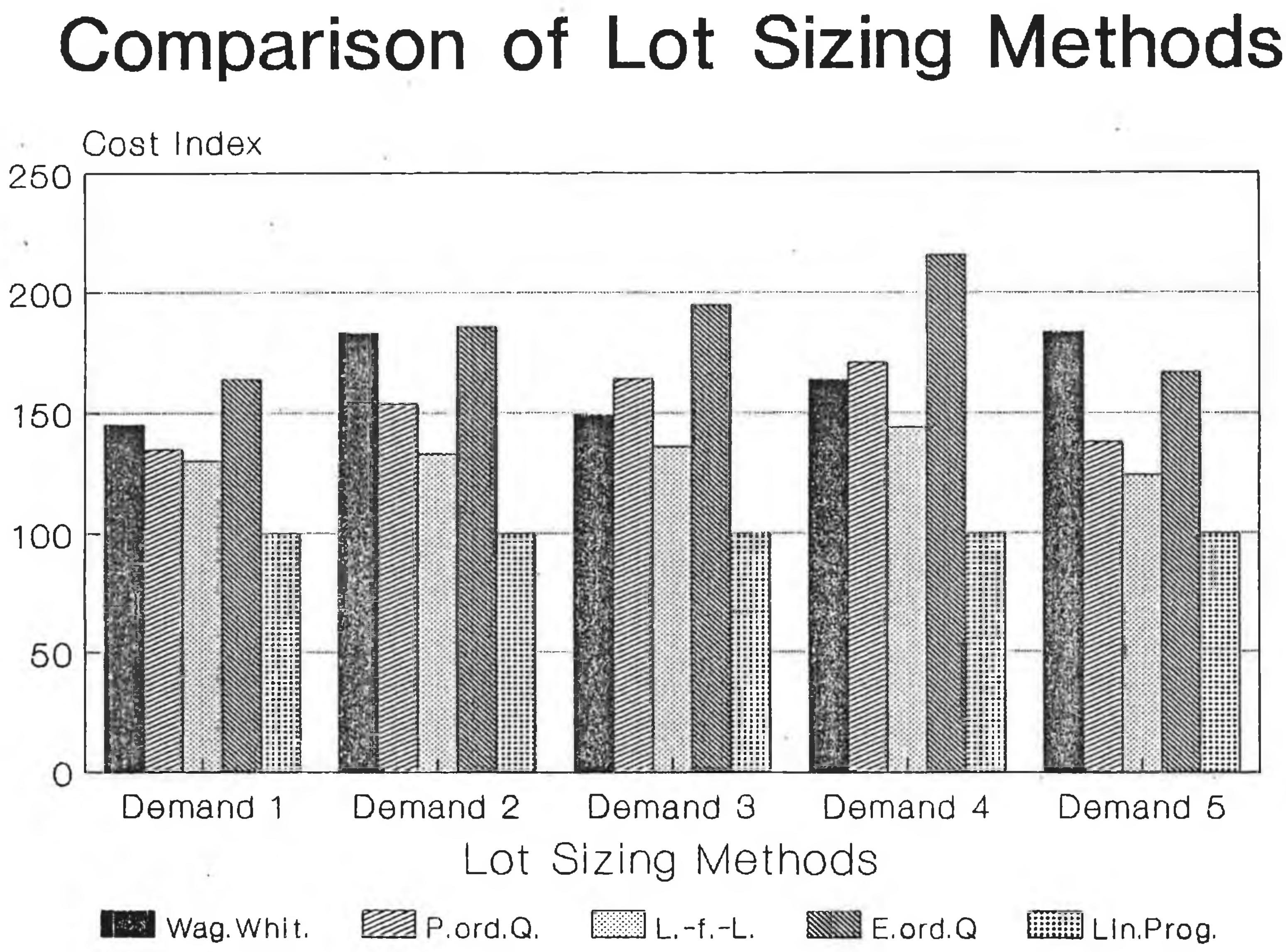

Comparison of Lot Sizing Methods
Cost Index
250
200
150
100
50
0
Demand 1
Demand 2
Demand 3
Demand 4
Demand 5
Lot Sizing Methods
Wag.Whit.
P.ord.Q.
L.-f.-L.
E.ord.Q
Lin.Prog.

Fig.(6.16)

CHAPTER 7

KANBAN

7.1 TYPES OF KANBAN CARD

Kanban is the name which has been adopted to describe the method of controlling material on the factory floor. It is the Japanese word for card, and came about due to the extensive use of cards (and or signals) within Just-In-Time Systems in Japan. Two main types of cards are in evidence:

1. Production Kanban
2. Withdrawal (Move) Kanban

A production type Kanban is used to initiate production within a given work centre. The card contains certain limited information about the piece to be processed such as item code, description, storage area and type of processing required. The card remains within the bounds set by the work centre, and associated input/output buffers and kanban posts.

A withdrawal or move Kanban, is used to withdraw material from a previous process. This type of card must necessarily move between adjacent work centres. Supervising material flow from the output buffer of the feeder work centre to the input buffer of the processing station. A withdrawal card, contains information regarding item codes and description, preceding and actual processing work centres and withdrawal quantities.

The terms withdrawal and production Kanban, have two meanings. Primarily they are used to describe cards which control both intra and inter production processes which occur in a normally operating repetitive manufacturing environment. Secondly, they are used generally to describe a variety of cards which may be required to ensure a successful completion of the whole manufacturing process, (Monden [45]).

A supplier Kanban, (withdrawal type) is used as the name suggests to obtain raw materials from suppliers. The Kanban contains lists of instructions regarding the delivery of these materials. A subcontract kanban is similar to the supplier kanban but refers to subcontract agreements.

If production on an assembly line is being fed by parts manufactured in a machine shop, - forging, die casting etc. The idea of production, withdrawal Kanban must be extended to the machine shop. Here where batch production predominates, the two types of Kanban are collectively termed signal Kanban. The production ordering Kanban, which operates like a two bin system is called a triangular Kanban, and the withdrawal kanban, which operates in a similar fashion is called a material requisition or rectangular Kanban.

Within any manufacturing environment deviations from the plan will occur. Several types of kanban are available to deal with these problems. Express Kanbans, which take the form of both production and withdrawal Kanban, may be introduced if a preceding station runs short of parts. Emergency Kanbans, are introduced if a particular work centre has a greater defect percentage than expected. Again emergency Kanbans take the form of both production and withdrawal kanban and are removed from the system as soon as the correct compensation has been made. A through Kanban is a production ordering Kanban which also acts as a withdrawal Kanban. Its main application would be in process type plant areas, where production at one process area is immediately followed by processing at the next process, via and automatic link/chute between processes. Alternately a common Kanban is a withdrawal Kanban which performs the dual functions of both withdrawing and producing. The two processes involved must be distinct but very close together.

7.2 <u>RULES ASSOCIATED WITH KANBAN OPERATION</u>

In much of APICS literature describing the emergence of MRP II in America, a great deal is made of the need to establish formal procedures, from within which MRP can operate efficiently. In some respects, kanban, which has no central control mechanism, unlike that of MRP, requires that even greater emphasis is placed on the establishment of these procedures.

The first rule of Kanban production and its' associated corollories echoes this sentiment.

Rule 1 "The subsequent process should only withdraw the necessary products from the preceding process and in the necessary quantities at the correct point in time".

Corollories
1. A kanban should always be attached to a physical product.
2. Any withdrawal greater than the number of kanban should be prohibited.
3. Any withdrawal without a kanban should be prohibited.

Together, the above rule, and its corollories place control of the withdrawal process form one work centre to the next, in the hands of workers on the factory floor.

The second rule for kanban production describes the quantities in which production takes place. Again, unlike MRP, where requirements for each and every work centre are determined by a central control, the correct production quantities are determined by the worker based upon quantities withdrawn to feed subsequent processes.

Rule 2 "The preceding process should produce its products in the quantities withdrawn by the subsequent process".

Corollories
1. Production greater than the number of kanban sheets must be prohibited.
2. When various kinds of parts are to be produced in the preceding process their production should follow the original sequence in which each kind of kanban has been delivered.

The second corollory, underlines the need for set-up time reduction, if kanban implementation is to be successful. If set-up times at the preceding process are prolonged then there will be a long delay between request and delivery of parts, disrupting the flow of parts. In effect a bottleneck is created.

One of the major differences between Kanban and MRP, is that MRP in the simplest sense operates on the pretence that nothing can go wrong. When it does, all the information regarding the incident is feed back into the computer (closing the loop), and new decisions are made at this central control, to compensate for the incident. This information flow can be very time consuming. Conversely, Kanban, in realization of this time delay, deals with incidences as they occur on the factory floor. This is accomplished in some respects by making the operator, responsible not only for the correct production of parts, but also for the quality of production. Rule three states.

Rule 3 "Defective products should not be conveyed to the subsequent process".

If defective parts are conveyed to the subsequent process, the process runs short of parts, and line stoppage results. The cause of the quality problem, is also of prime concern to the operator. Badly kept tools, routines, labour hours, cause quality problems, and must be accounted for by the operator, in his goal to perform Total Preventative Maintenance.

In a factory which is driven by MRP, or in fact, by any push system, work-in-progress (WIP) can make up a high percentage of overall factory inventory. Unless interpreted correctly, the level of WIP in a system, can falsely represent now well a system is operating. High levels of work-in-progress serves to hide operating problems and in deference to this, JIT practitioners refer to lowering the river of inventory to expose the rocks (operating problems). Using a Kanban system, (as will be explained Section (7.4.1)), it is the number of kanban cards in the system, which ultimately decides the level of inventory in the system. Using a dual card system, at a particular point in time, assume no production at work station y, and empty kanban posts, the maximum WIP level at the input and output buffers is determined by the number of withdrawal and production kanbans respectively. Decreasing the number of cards therefore reduces the amount of WIP in the system. Rule four states.

Rule 4 "The number of kanbans should be minimised".

Reducing the set-up time, means that the lot size can be reduced, which in turn, can cause a lead time reduction. Noticeable reductions in cycle time, mean that the number of parts in simultaneous production can be decreased. This is achieved by removal of kanban cards from the system. The determination of an optimum number of cards to control the systems performance must then be followed by policies to vary cycle times in response to fluctuations in demand. For example, if demand is increased the system which is operated by a multi-function work-force can move workers from a low demand to a high demand area thereby increasing capacity. Any problems which surface during operation are immediately identifiable, due to low WIP values, and solutions can be found quickly.

An MRP system, generates requirements for each and every process within the system, at fixed intervals based on demand. Dependant on the type of system in use, these requirements are then used to generate production schedules. Large fluctuations in demand or deviations from forecast, require rescheduling for each and every process within the system, which can cause unnecessary time delays between due date and finish date. Unlike MRP, kanban requires only one valid schedule. The final assembly schedule which dictates the daily build quantities. If at the end of the day, a change in the plan is required this can easily be accomplished by changing only this one schedule. The final rule for kanban production states.

Rule 5 "Kanban should be used to adapt to small fluctuations in demand".

If the final assembly schedule is balanced (uniform workloads) over a particular time span, and a sudden increase in demand is forecast (known) in the near future. Rather than waiting until the period becomes current, and issuing production schedules to the floor, kanban advocates the fine tuning or rebalancing of the final assembly schedule until the schedule is again on target. The downstream processes, are not issued any formal notice of the change, all that happens is that cycle times may be minutely increased, (Schonberger [32], Monden [45]).

7.3 SMOOTHING PRODUCTION

Just-In-Time production requires that variations in demand are hidden beneath a developed uniform workload. This idea of adapting production requirements to demand variations is referred to as production smoothing.

Smoothing necessarily requires deviations from the more typical batch manufacture, where a single product may be produced in large batch sizes, to a situation where a single line may produce many varieties of product each day in response to customer demand. The method of adaptation occurs on two levels and is an integral part of the development of the final assembly schedule. JIT manufacturers would initiate production plans by the development of a yearly production plan in terms of model and quantity, a two step monthly plan then follows, consisting of:

A. Models and quantities, two months previous.

B. Detailed Plan, one month previous.

If the yearly plan deviates markedly from the original plan, then this requires a change in the monthly plan, - monthly adaptation. The monthly plan is used to generate, daily production quantities in terms of models and model variations. For example if 100 units per month of model A are required and, there are 20 working days per month,

TABLE 7.1 Smoothing Production

Type	Monthly Demand	Av Daily Output	Cycle Time
A1	20	1	480 min/shft
A2	40	2	96 min/unit
A3	40	2	
	100	5	

The correct proportions are listed in Table (1). An increased demand of 20 units/month, would cause an increase of 1 unit per day, requiring fine timing of production using Kanban and a revised sequenced schedule.

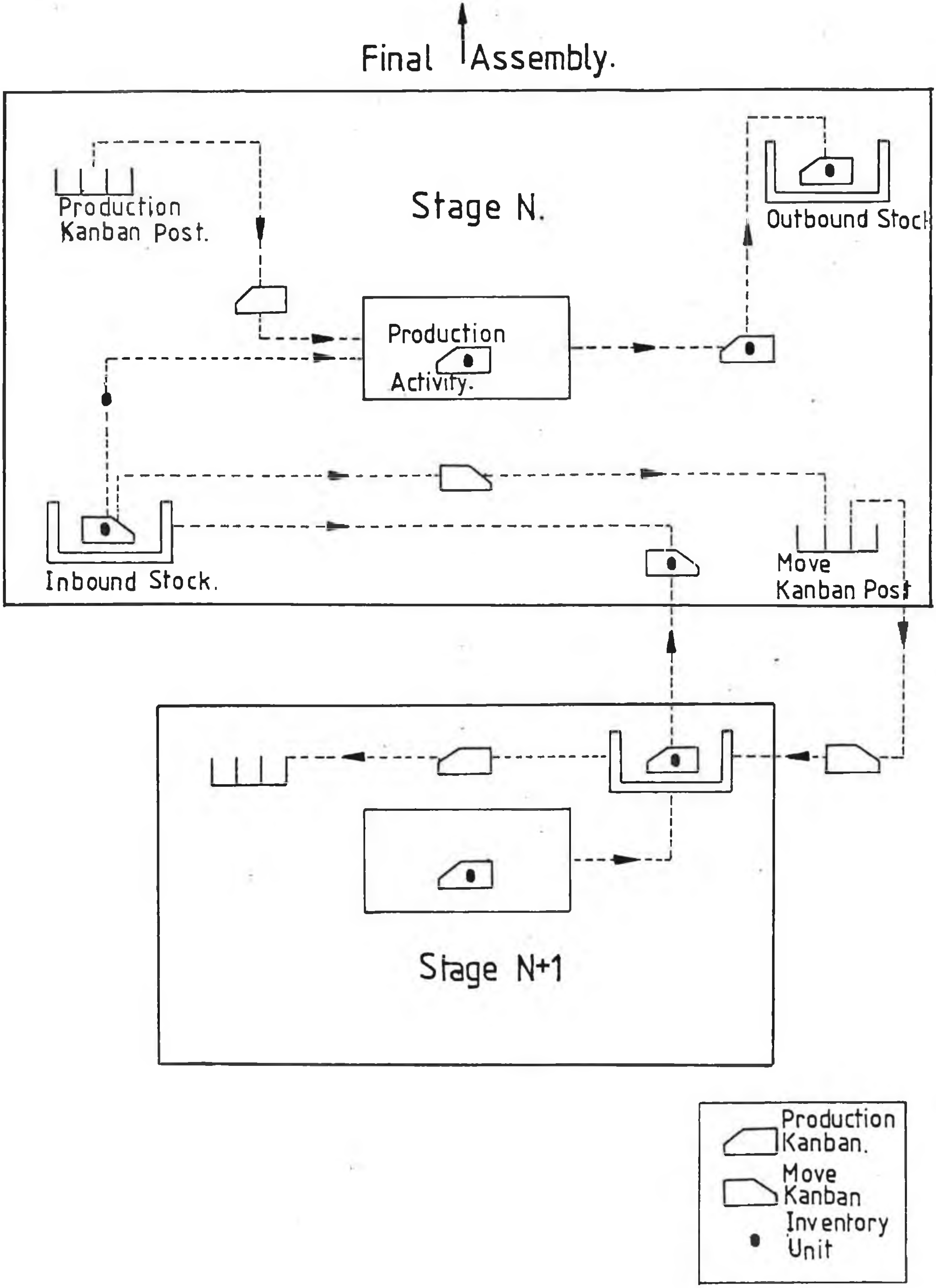
Large increases or decreases in production requirements require more tangible changes to the existing production system. Increasing overtime, hiring temporary workers, moving skilled workers, making use of slack machinery are all incorporated to help with increased deamdn. Slumps in demand, are not followed by massive redundancies, although temporary workers would be let go. Idle workers are gamely employed in quality circle meetings, practising set-ups, maintenance etc.

7.4 KANBAN MODELS

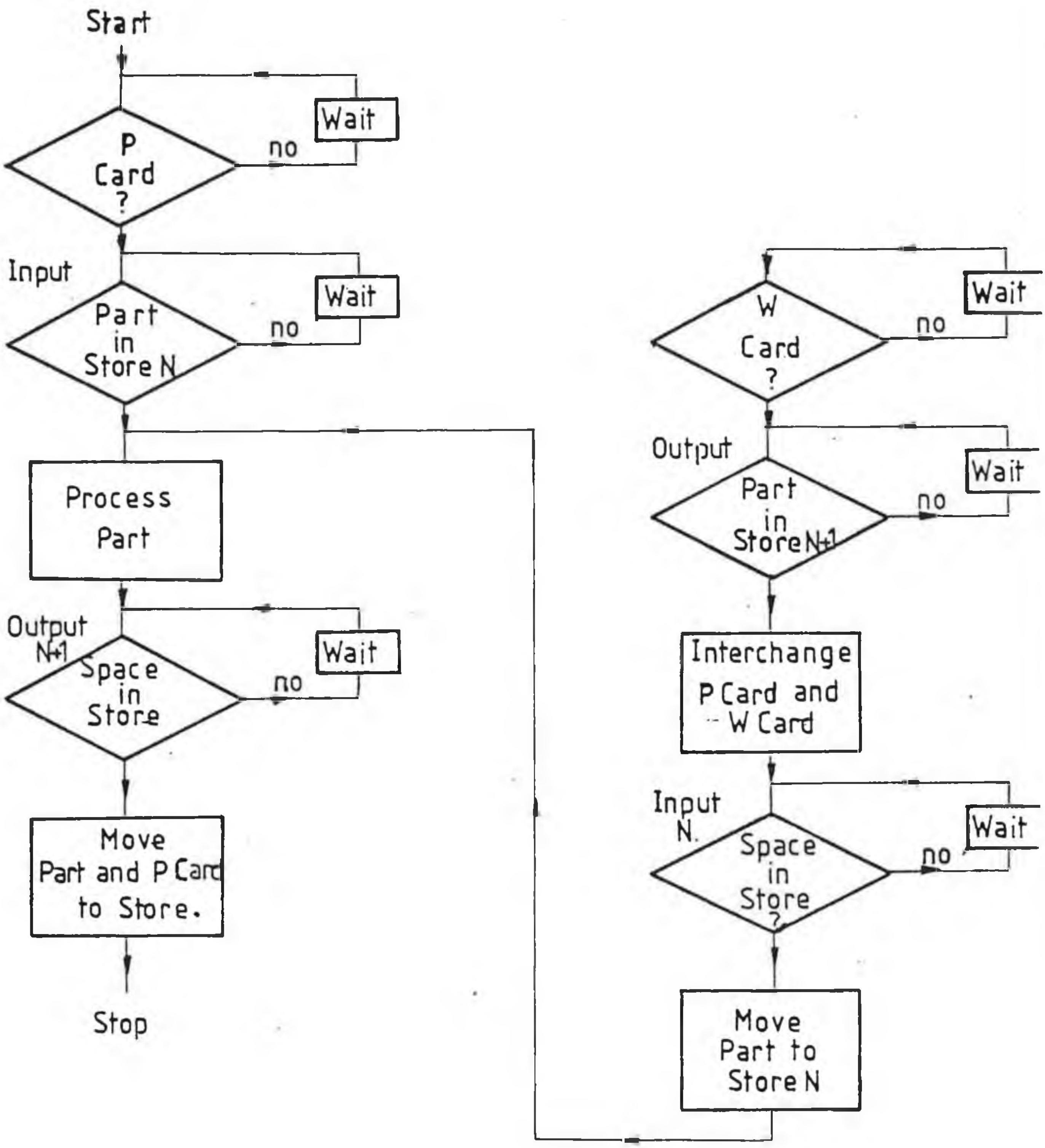
7.4.1 Two Card Model

In order to operate a two card kanban system correctly, each production process requires two buffers, input and output buffer, two kanban posts, one for production cards and the other for conveyance cards, and inventory in each buffer. Fig. (7.1), shows each of these elements, at two processes within an assembly line, where material, is processed at stage N+1, and then moved to stage N. (Villeda [24]). Daily requirements are introduced to the line via a daily requirements schedule at final assembly. These requirements are then transmitted to every stage on the line through the use of production and withdrawal kanban.

Before production is initiated the line is in a state of balance, with empty kanban posts and input and output buffers filled to capacity, accompanied by the appropriate kanban card, (material in the input buffer is accompanied by withdrawal cards) at each and every station on the line (Table (7.1) line a). The introduction of the schedule initiates production in the following manner.



Flow of Kanban Cards(Two Card System). Fig. (7.1)



Two Card Kanban. Fig (7.4)

TABLE (7.2): Postion Of Cards/Processed Units At Certain Points In Time

	Stage N+1				Stage N+2 (Final Assembly)
	Production Card Post:	Input Buffer:	Output Buffer:	Withdrawal Card Post:	Withdrawal Card Post:
(a) Balanced	----	$1^u{}_1$, W_{N+1}	$1^p{}_2$, P_{N+1}	----	W_{N+2}
(b) Unbalanced	P_{N+1}	1,W_{N+1}	----	----	
(c) Unbalanced	____	----	$1^p{}_1$, P_{N+1}	W_{N+1}	
(d)	----	$1^u{}_3$, W_{N+1}	$1^p{}_1$, P_{N+1}	----	

W_{N+1} Withdrawal Card Stage N+1; P_{N+1} Production Card Stage N+1

$1^u{}_k$ Unprocessed Material Unit (k=1 k, different units);

$1^p{}_k$ Processed Unit

A withdrawal card (W_{N+2}) is taken to the penultimate station (N+1) on the line, (which is in a state of balance, and the appropriate amount of material carried to final assembly. The production card which accompanied the material in the buffer is replaced in the production kanban post. (Table 7.2 line b). The station is now unbalanced, and in order to return to a state of equilibrium must unbalance the preceding station.

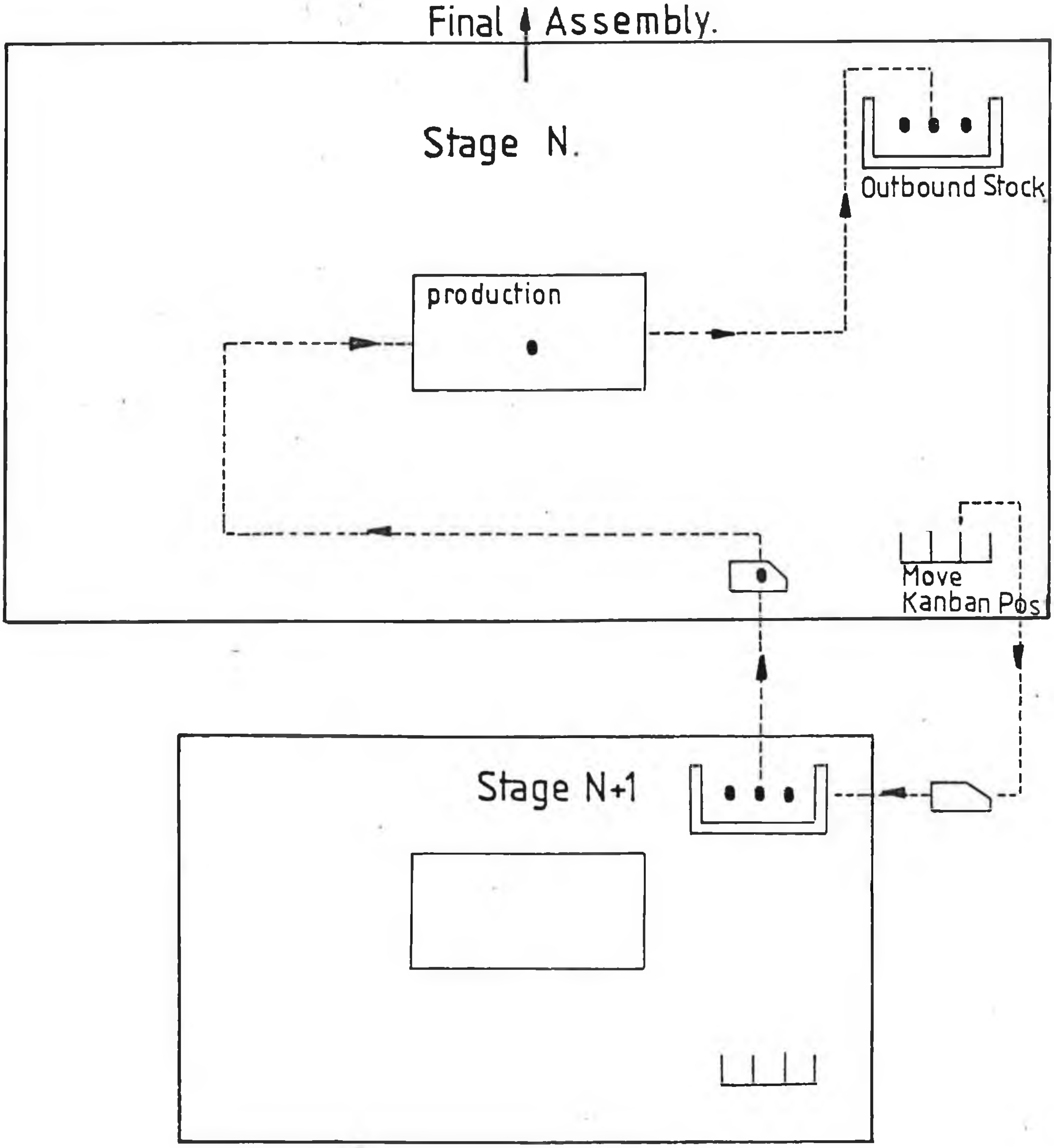
Balancing or returning to equilibrium is achieved in two steps. Firstly the production card is removed from its post, and taken to the input buffer, and the correct amount of material removed for processing. The accompanying withdrawal card is replaced on its post. The input buffer is now empty, and the output buffer is again full (Table 7.2 line c). The withdrawal card is then carried to the input buffer of the preceding process and the correct amount of material removed. This material is then placed in the input buffer of the current station accompanied by the production card. The station is again balanced. (Table 7.2 line d). The preceding station is now unbalanced. Because each station is successively unbalanced, and strives to return to equilibrium, a type of action/reaction ripple is sent down the line from final assembly.

The level of inventory at both input and output buffers, when the system is in a state of equilibrium (i.e. the maximum WIP level) is set by the number of cards for that process. The exact number of cards introduced is a management decision although formulae have been developed. This number however should be reduced as low as possible, without causing any disruption to the systems performance. Fig. (7.4), is a flow chart representing the various decisions which must be made in order to bring the system back to equilibrium.

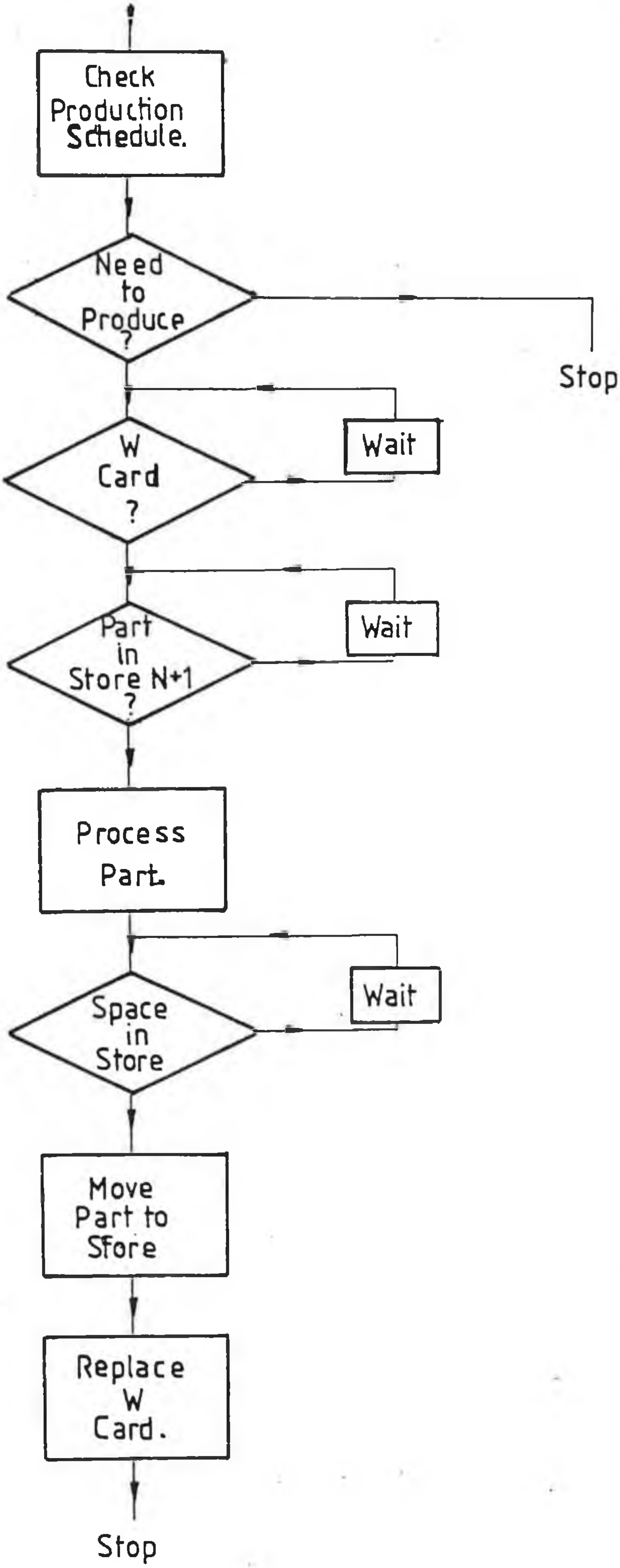
7.4.2 Single Card Kanban

Single card kanban varies slightly from the dual card system, in that production is carried out at each station, based upon a production schedule. Withdrawal of parts however occurs via kanban cards. In order to operate the system correctly, each process requires, an output buffer filled to capacity, and a withdrawal kanban post. (See Fig. (7.2)). The line is in a balanced state, when both the output buffers and kanban posts are filled with both material and cards respectively.

Production is initiated as follows: A final assembly withdrawal card is brought to the preceding stage, stage N and the appropriate material removed, and immediately processed at final assembly. Stage N is now unbalanced, because the stock level in the output buffer is less than that at a balanced state. In order to regain balance, a withdrawal card is brought to the preceding stage, and the correct part processed at stage N, and placed in the output buffer. The withdrawal card is replaced on the post. as soon as production is initiated. Stage N, has now regained equilibrium, bu the preceding stage is now unbalanced. Each process is successively unbalanced in a similar fashion to that of two card kanban and so again an action/reaction ripple is sent down the line. Fig. (7.3) shows a flow chart of decisions required for each process to return to equilibrium.



Flow of Move Kanban Cards(Single Card Kanban). Fig.(7.2)



Single Card Kanban. Fig.(7.3)

CHAPTER 8

A SIMULATION STUDY OF KANBAN SYSTEMS

8.1 SIMAN AND SIMULATION

8.1.1 Introduction

Simulation is used in a wide variety of fields to mimic the dynamic behaviour of real systems, as time proceeds. A system, may be defined (Schriber [49]), "As a collection of interrelated elements which work together co-operatively for the purpose of achieving a stated objective".

Two basic types of simulation exist, namely, discrete event and continuous simulation. The former describes a system in which all changes in state occur at specific points in time. (eg. parts arriving at an input storage buffer). The latter type - continuous - refers to the case where all changes in state occur continuously over time (eg. chemical processing). Hybrid systems, made up of both types also exist.

Within the confines of a manufacturing system, simulation may be undertaken for a wide variety of reasons. It may be used to monitor or evaluate proposed changes in resource capacity requirements, where the resource in question may be a machine, or personnel, transporter mechanisms, or even work-in-progress buffers. When modifications, or complete replanning of specific system areas, such as a change in machine layout, or change in product mix, or even a change in product scheduling method is suggested, simulation can be used to great effect, in evaluating the various proposed methods.

8.1.2 Introduction to SIMAN

In order to perform a simulation, a simulation model must be built. Various high level computer languages exist for this purpose - GPSS, SLAM II, GALS etc.

SIMAN is a general purpose simulation analysis package, which allows the modelling of combined discrete/continuous systems.

The modelling framework of SIMAN, allows the various models to be logically split into two distinct and very separate sections. The first of these sections is termed the system model - and defines the "Static and dynamic characteristics of the system". The second section, termed the experimental frame, "defines the experimental conditions under which the model is run" (Pegden et al [50]). Various parameter values, resource capacities, and processing sequences are defined within this section. This separation of the model into two distinct sections means that the same model can be run under a variety of performance conditions, using different experimental frames. Before the simulation run, both sections of the model must be compiled and linked together.

The standard form of the output generated by the SIMAN program consists of an average of model state transitions as they occur over time. The actual transitions of interest are stated as performance measures within the experimental frame. The period of time which the statistics reflect is also listed in the experimental frame. The generated output file may be investigated further through the use of the SIMAN output processor.

A SIMAN system model file is specified in terms of blocks. To facilitate programming each block has an associated pictorial symbol and top down flow charts can be drawn and ten basic building blocks to define a system model. The experimental frame, is defined in terms of elements. Each element providing more information about the system, The parameters element for example, gives the various parameter for any experimental distributions referenced in the model. The resources element names and defines the capacities of the various resources. The transporters element does the same for transporters. The sequences element defines the various sequences between machines which an entity might take. Once the model file has been developed, the experimental frame, is relatively easy to write. Parts, and people etc, within a SIMAN file are represented by entities, which flow through the system. Entities may be personalised by assigning various attributes (A(*)) to them.

8.2 SIMULATION OBJECTIVES

Many authors have investigated the effects of the process time imbalance (see Sarkar et al [22]) on push production systems. Recently this work has been extended to cover pull systems also. Villeda et al [24], has done work in this area.

One type of process time configuration - referred to as the "Bowl - Phenomenon" is thought to be caused by:

A. Imbalance in work station mean

B. Imbalance in work station variability.

This study will examine the effects of both, on systems performance, with a bowl type configuration and with the alternate configurations described in Section (8.6). Any effects in system performance due to process time variability can be overcome by increasing the level of work in progress (WIP) within the system. WIP however is also undesirable, and a secondary objective therefore is to find that value of maximum buffer stock which allows control of system performance through process time variation. This also allows an investigation in the change in system performance parameters with an increase in the number of cards within the system.

8.3 PERFORMANCE MEASUREMENTS

8.3.1 Introduction

The problem which confronts any model builder is to accurately ascertain how the system is performing. One of the more obvious measures is the time a part spends in the system, from creation to completion. This type of measurement, which is purely observational is easily accomplished by counting the entities as they pass some point in the model, and noting the time which has elapsed. Cycle times for parts within the system may be found in this manner.

In order to find data on such topics as resource utilization or the average number of parts in various buffers, time dependant performance measurements muct be called upon. Time dependant data consists of a sequence of values, the value of which persist over some specified amount of time. This value must be weighted by the amount of time that for which value exists. Time dependant data must be recorded whenever the value of the time dependant variable changes. If the number of entities (parts) residing in a particular queue are of particular interest, then each time the length of the queue varies both this value, and the time for which the queue remains at this length must be recorded. The average value of machine utilizations, may be computed in this fashion.

The SIMAN language, allows easy collection of both observational and time dependant data, through the use of a TALLIES and DSTATS elements respectively.

8.3.2 Evaluating The Kanban Models Performance

The performance measures used to evaluate the models performance were of two types: - primarly and secondary measures. Primary performance measures, were those from which it is immediately possible to gauge a systems performance, namely the production rate (per shift) and the level of WIP in the system. Secondary performance measures, which provide more information about the internal working of the system were also evaluated. These measures included mean resource utilization figures, and also mean waiting time for final assembly. (ie. the length of time a part waits for all three parts to be made available).

8.4 THE PROBLEM SPECIFICATION

A production line is perfectly balanced, when the processing times at different stages are the same. In this situation the operators at each station have an optimum inventory pile to work from and no blocking or starving occurs at any work centre. Blocking is said to occur (Silver et al [51]) when a work station, having completed a part, finds the next buffer, filled to capacity and therefore must retain the part until a space becomes available. Starving occurs, when a work station, having completed a part, finds that the input buffer is empty and therefore must remain idle. In reality however, perfectly balanced lies are a fallacy due to uneven processing times, resource capacities, operator inefficiencies etc. a pull system, therefore, like a push system will necessarily experience imbalance at differing work stations.

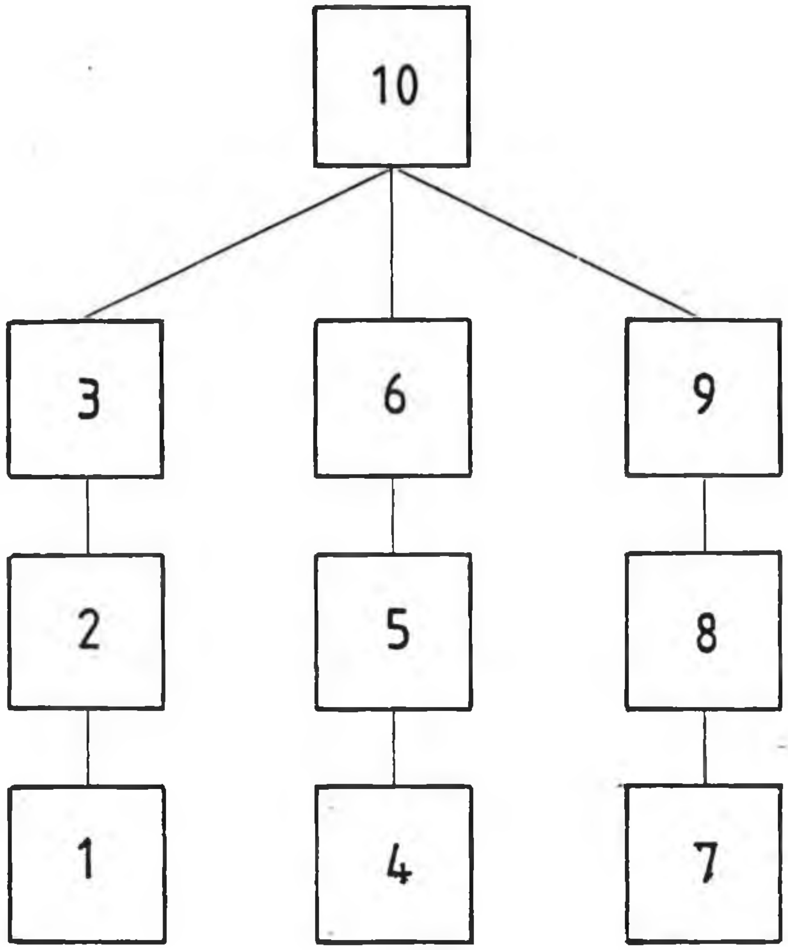
This imbalance in the system results in changes in WIP levels, changes in resource utilization and changes in output rates. Simulation experiments such as will be described in future sections, can provide invarluable help to production controllers. The effect of various imbalance configurations can be analysed in terms of the various performance measurements, and the possibility of remedial action discussed.

8.5 THE KANBAN MODEL

8.5.1 Understanding The Model

The two card kanban system, described in Chapter 7, provides the basis upon which the SIMAN model described is built.

The model is driven by a final assembly schedule (FAS) which initiates production at work stations 1,4 and 7. (Fig. (8.1)). Within a real kanban system however, production is initiated at station 10, with the parts in the input buffer being processed to meet the demand stated in the FAS. This in turn initiates production at stations 3,6 and 9, and so on towards the first work station in each line. Parts held at storage buffers, therefore do not go through the complete processing cycle. However, parts being removed from raw material and placed in the input buffer at stations 1,4 and 7 do go through the complete cycle from the initial stations to final assembly. The developed model, ignores the parts left at interstage buffers, since we are only interested in overall cycles times. It is therefore assumed that a call for parts at final assembly is also a call for parts at stations 1,4 and 7.



Workstation Layout. Fig.(8.1)

The described model (Chapter 7), refers to withdrawal and production kanban cards. These cards set the level of buffer stock at the input and output buffers. When all the cards are in use, the number of parts in the input buffer cannot exceed the number of withdrawal cards and similarly the number in the output buffer cannot exceed the number of production kanban. With only one part being routed from one station to the next, it is possible to allow the set maximum level of work in progress at input and output buffers at each station represent the number of withdrawal and production kanban respectively.

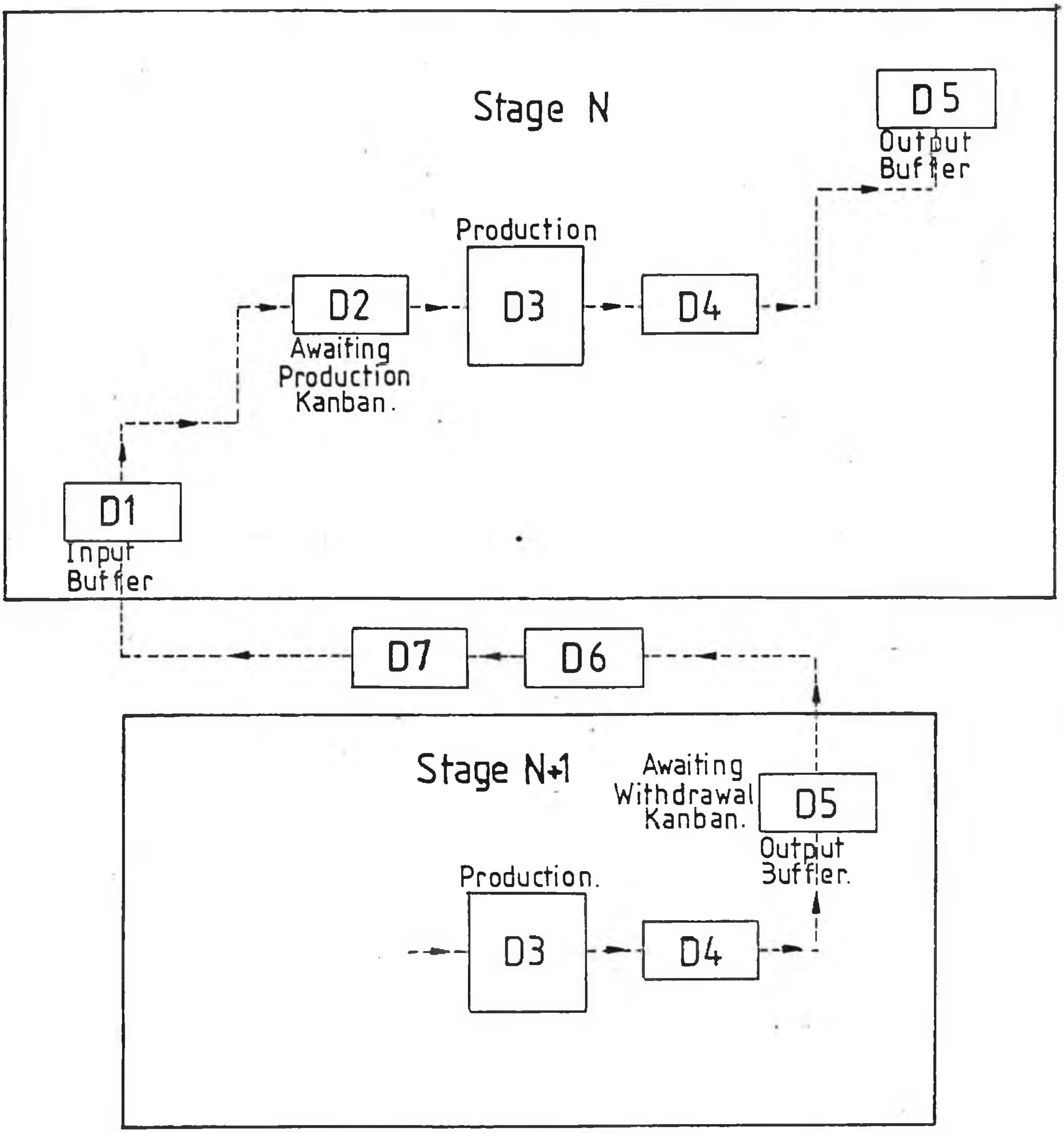
8.5.2 Time Delays Within Kanban Model

For each operation within the system, there can be at most six types of delays. The first of these delays is a queueing time delay, and is the elapsed time from when a part enters an input buffer, to that time when it seizes the top position in the buffer. This time is not fixed within the model, but rather is dependant upon system performance and is determined by the system. (Fig. (8.2), D1).

The second time delay occurs if a part at the top of a buffer (assuming first in first out) must await the arrival of a production kanban, in order that production can be initiated. If the correct card is not available this means that the actual machine involved in processing is busy. (Fig. (8.2) D2).

The next time delay which occurs is the actual processing time at the machine in question. This time delay is built into the model, and impacts on the systems performance (Fig. (8.2) D3).

Once a part has been processed, the part must be moved to the output buffer. However, if the output buffer is filled to capacity the part must remain with the machine until space is available. This time delay, is obviously again dependant upon the systems performance (Fig. (8.2) D4) (Blocking).



Key.

Code	Delay
D1	Queue (Input Buffer)
D2	Wait (Machine in use)
D3	Process Time
D4	No Space in Buffer (Output)
D5	Queue (Output Buffer)
D6	No Space in Buffer (Input)
D7	Routing Time

Time Delays Within the Kanban Model. **Fig. (8.2)**

The next time delay to be incurred is that of storage time in the output buffer, ie. the time the entity takes to become current. (Fig. (8.2) D5).

When the part arrives at the top of the store a check must be made before the part is routed to the next station. If withdrawal cards are in use, the arrival of a withdrawal card signifies a positive check and the part may be moved. Otherwise the part must reside at the top of the store until a card becomes available. (Fig. (8.2) D6).

A routing time, ie the time it takes for a part to be routed from one station to the next may also be incurred. This time, like operating times, is built into the model.

8.5.3 Assumptions Of Model System

1. The system processes only one product type.
2. This product is produced on the multi-line, multi-stage assembly system laid out in Fig. (8.1).
3. Each process shown in Fig. (8.2) has two associated buffers - one for both input and output stock.
4. The amout of stock allowed to reside in these buffers, is set by the maximum number of move and production kanbans existing at that work centre.
5. Final assembly is producing Just-In-time, as dictated to by requirements.
6. Processing times at each work station are assumed to be normally distributed, with a mean of 15, unless otherwise stated. Three different coefficients of variation (CV) are used.
7. Demand for parts at final assembly occurs exponentially, with a mean of 8 ($\mu=8$).
8. The routing time between work station is assumed to be zero.
9. No scrap or defective parts are produced at any work station.
10. The objective is to maximise the number of parts/entities completed per 480 min shift.

8.5.4 Simulation Model - SIMAN

A simulation run using SIMAN, requires at least two files.- A model file and an experimental file. The model file describes the flow of parts (entities) through the various processes within the model. Each piece of code is called a block. The experimental file is used to provide more information about the blocks in the model file. The files used to simulate the kanban model are listed in Appendix (4).

The Model File

The first section of the model file is used to generate a final assembly schedule. The time between creations are exponentially distributed. As explained in section (8.5.1), a call for parts at final assembly, equates to a call for parts at the first station in each line, and therefore each time a part, is written to the final assembly schedule, three dublicate entities are created, and assigned their respective attribute values. These entities are each sent on separate routes towards final assembly.

The second part of the file deals with entity flow through the assembly system. The system (Fig. (8.1)) shows ten processing areas and each of these are correspondingly modelled as work stations 1 through 10. Each work station contains three vary important elements - An input buffer (queue M, where M is the number of the present station), the actual processing resource (Work Centre M), and an output buffer, (Queue M+30). Within a kanban model, the movement of parts from buffers to work centre, within a station, and from buffer to buffer between stations must be carefully controlled. This is achieved within the model by use of a SIGNAL and WAIT block combination. One of the part specific attributes, an entity gains on creation is the station number of the next station to be visited by that entity. (This is automatically updated via the SEQUENCES element as a part enters a station). Before a part can be moved from its present position at an output buffer to the input buffer of the next station, a check must be made to see if the input buffer has space available. The capacity of each input buffer is specified as a global variable (X(A(1)). If there is no space available at the input buffer the part (entity) is held in a WAIT block until a space becomes available, and a signal corresponding to the first operand of the WAIT block is received. This signal is sent by a SIGNAL block as soon as the work centre has been seized, indicating that a part has been removed from the buffer. Once this signal has been received, the entity leaves the WAIT block, and checks again to see if there is space available at the buffer. If there is, the entity is sent to the input buffer, if not, it is sent back to the WAIT block to await another signal.

A similar situation arises when a part is moving from a work centre to an output buffer. A check is made to see if there is space available on the output buffer, if there is, the part moves, otherwise the part enters a WAIT block to await a signal, which is sent as soon as a part departs the output buffer. This time however signal values vary from 11 - 20, instead of 1 - 10.

The final assembly authorises production which is initiated at stations 1,4 and 7, (see section (8.5). It is therefore necessary to make three duplicates of the authorisation entity to send to each of these stations.

All the time assembly station are dealt with within the same macro submodel, and is necessary therefore to include a number of BRANCH blocks with this macro. When an entity reaches stations 3, 6 or 9, instead of checking immediately to see if there is space available at the input buffer of station 10, before being routed to station 10, an entity reaching any of these stations must wait until an entity has been processed at the other two stations. All three entities may then be simultaneously released and permanently combined, before, being processed at station 10.

In order to calculate the lead times for the various processes involved. Two modifier blocks must be introduced these are the MARK block and the INT block. The MARK blocks assigns to an entity specific attribute, the present time-tnow; and the INT block, accumulates the elapsed time between tnow and the time when the entity enters the associated TALLY block.

When production has been completed, and the entity has contributed to collected statistics, the entity has fulfilled its use and must be destroyed. This is again accomplished by a block modifier, - the DISPOSE block.

__The Experimental File__

As stated previously, the experimental file provides more information about the assembly system described in the model file.

The DISCRETE element places a limit on the number of entities which can co exist within the model at any time, and also on the number of stations, queues and entity specific attributes.

The RESOURCES element numbers and names the various resources within the model, but may also be used to provide more information on the available capacities of a particular resource, as time changes.

The model uses global variables to specify the maximum capacity of each stock point (ie the number of Kanban cards available). Values may be assigned to each global variable using the INITIALIZE element.

The SEQUENCES element is one of the most important of all elements. In its most basic form these block, specifies the various sequences, in terms of work stations by which an entity may traverse the assembly system. Each time an entity encounters a ROUTE block, with sequence as an operand, the SEQUENCE element must be referred to.

When an entity is routed to a station via the use of a SEQUENCE element, the entity is automatically given two new attributes, IS and NS. The NS attribute, corresponds to the sequene number currently, in use and the IS attribute, the current sequence index corresponding to that sequence number. Both of these attributes are updated on entering a station.

The SEQUENCE element may also be used to change the values of user assignable attributes. For example, the sequences element may be used to update the attributes associated with processsing times and the station to be visited. User assignable attributes are also updated when the entity enters a new station.

The PARAMETERS element is used to specify any parameters associated with distributions specified in the program. The first number in the distribution acts as an index into the parameters element.

The DSTAT and TALLIES elements are used to provide system specific information.

8.6 RESEARCH PROCEDURE

1. The developed model was run for a variety of parameter values. In the 'Balanced', 'Cantilever' and 'See-Saw' cases, processing times were varied from 5 - 25 min in steps of 2 minutes. The two 'Bowl' configurations were varied from 14-16 min in steps of .2minutes. (Each set of mean processing times were run with 3 variance values).
2. Unless otherwise stated, the number of production (and move) Kanban was set to 1.
3. The simulation program was run for one replication of 530 min with statistics being cleared after 50 min for the range of processing times and system configurations. Two random number streams were used.
4. The above procedures were initially carried out for four different unbalancing methods described below. Initially, the second stock point was assigned a capacity of zero, to increase the systems sensitivity.

Balanced Case

This is the base case for the study. The operation times at each workstation in each assembly line are normally distributed, with a mean of 15 minutes, and a variance of 1 minute, 3 minutes and 5 minutes.

In the proceeding experiments, which are conducted in each case for the variances listed above, when operation times are varied at certain stations, the unvaried station retains a mean of 15 minutes.

Cantilever Case

In this case the first station in each line is varied, form 5 to 25 minutes in steps of 2 minutes.

See Saw Case

Here the first and last stations in each of the three lines are varied. As the first station increases from 5 to 25, the last station simultaneously decreases from 25 to 5, in steps of two.

3 Stage Bowl

In this case again only the first and third stations are varied. Both stations are varied by a similar amount in the same direction - from 14 to 16 in steps of 0.2 minutes.

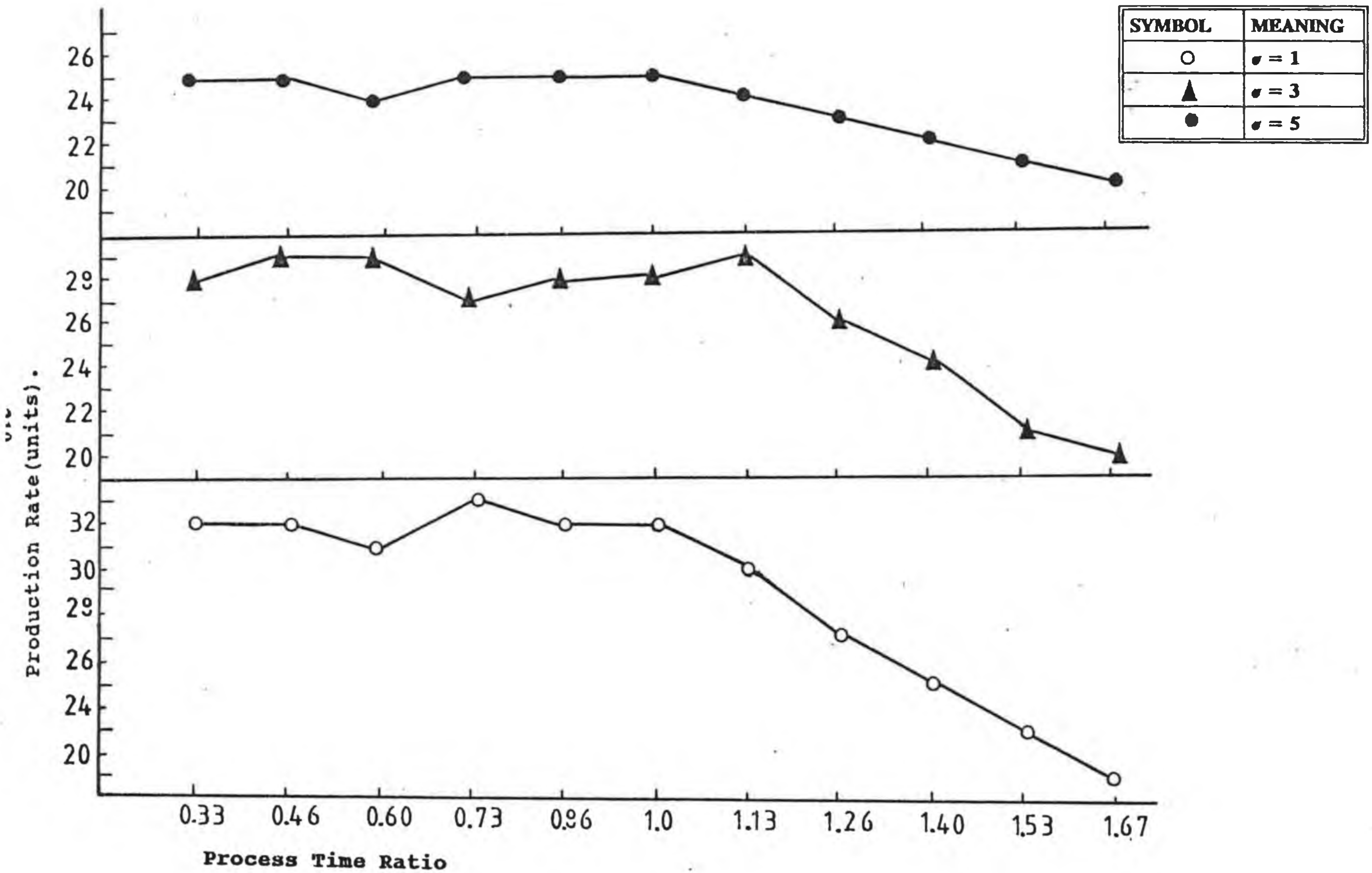
4 Stage Bowl

In this final case the second and third station in each line are varied, while the first station remains constant with a mean of 15 minutes. The stations are simultaneously varied over a mean of range 14-16 minutes, in steps of 0.2 minutes.

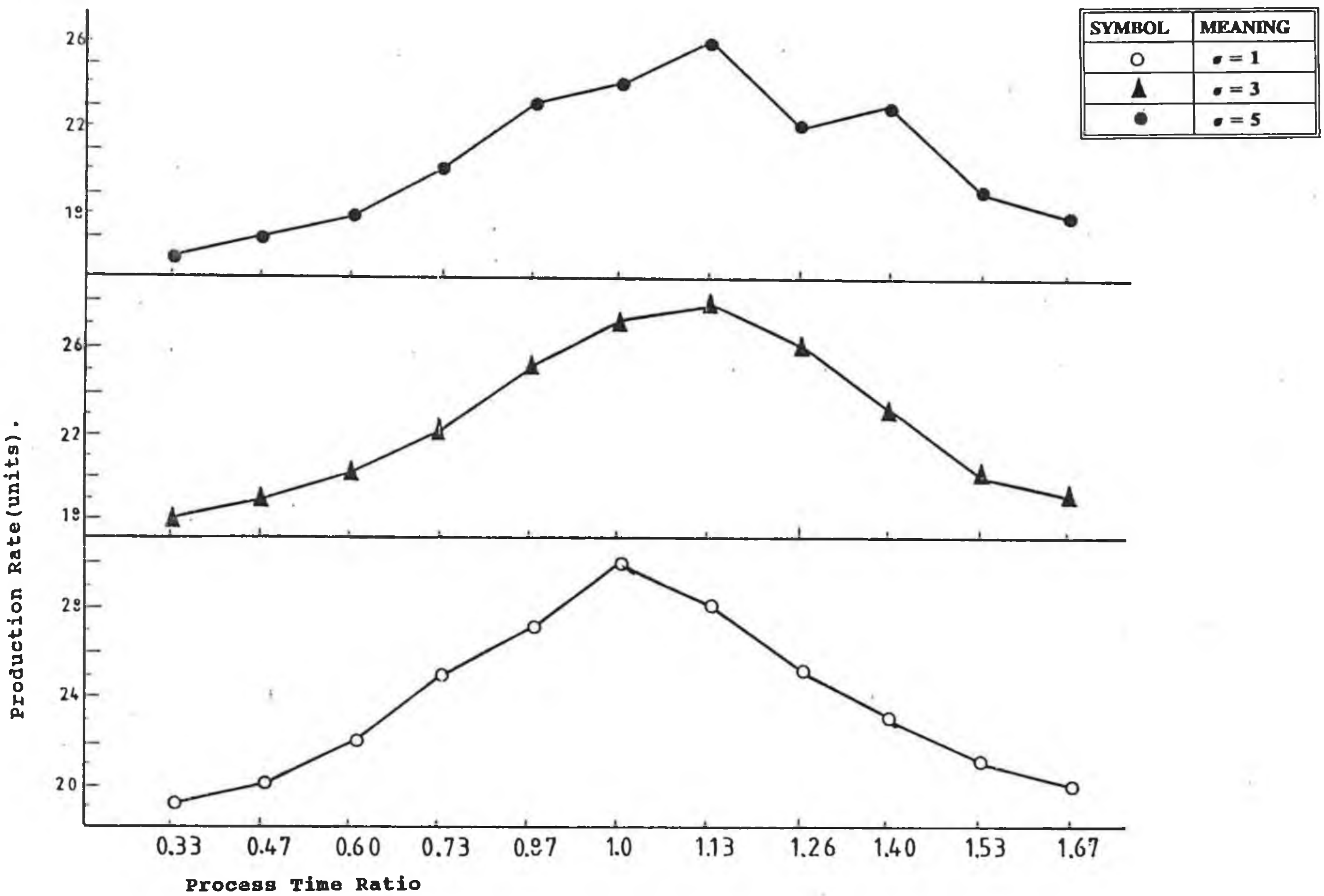
5. The unbalancing method with the greatest potential to increase the systems performance was identified, and steps 1-3 carried out using three sets of card systems.
6. The effect of variability at the final assembly station (for the config. used in step 5) was investigated, varying the processing time from 5 - 25 min, using the three variance values. Each run was carried out according to steps 2 and 3.

8.7 DISCUSSION OF RESULTS

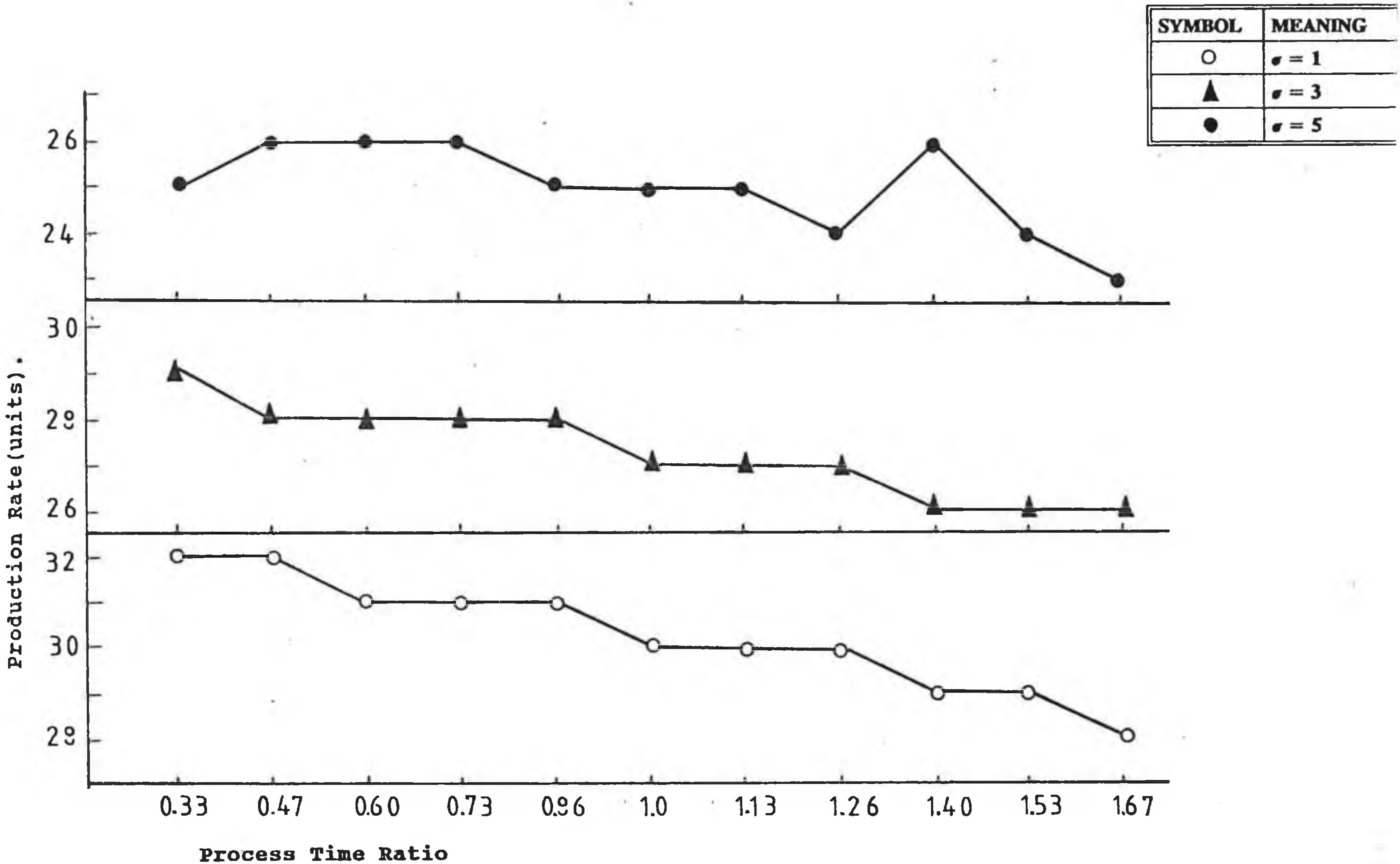
8.7.1 Investigation of the Unbalancing Methods



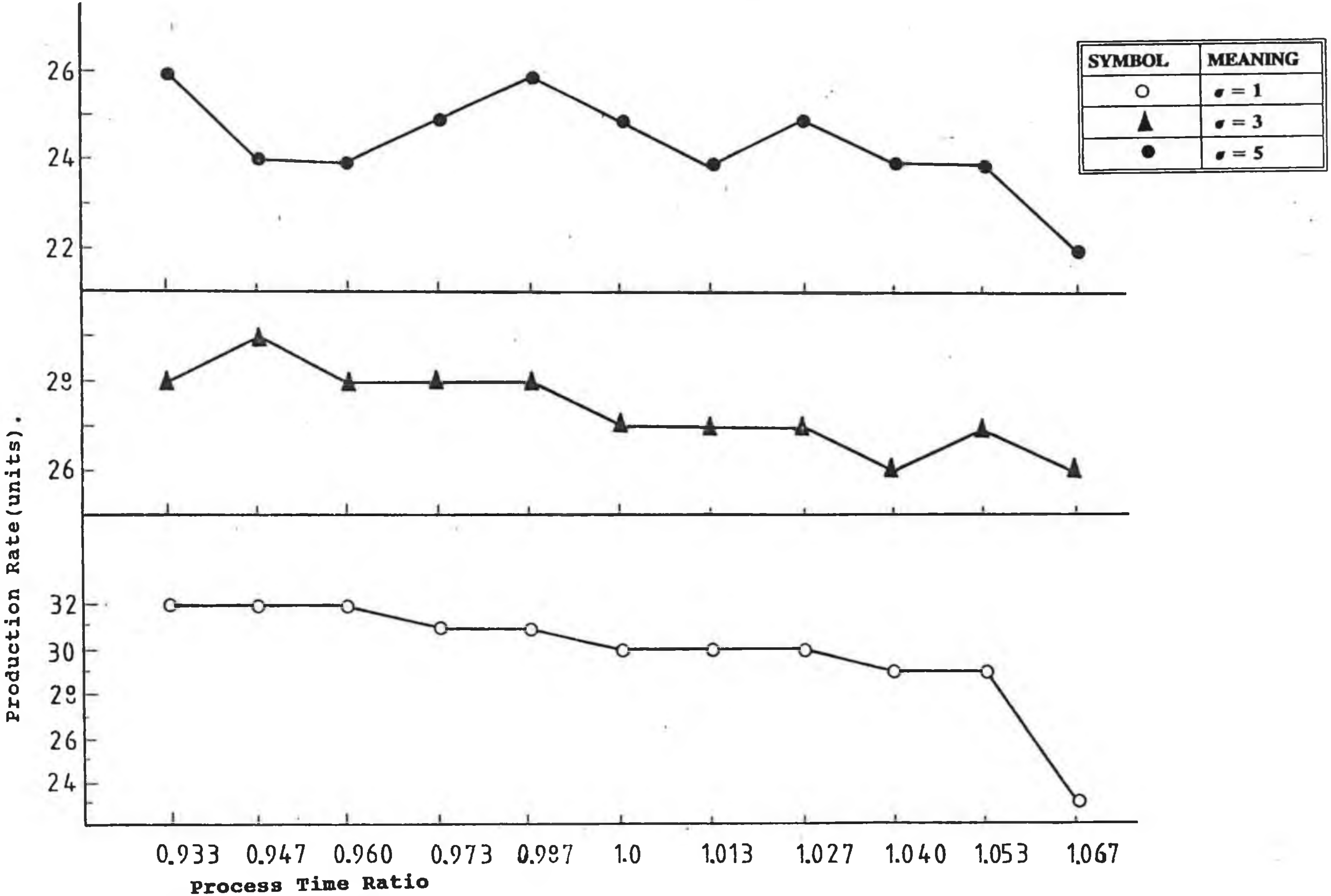
Production Rate Vs. Process Time Ratio(Cantilever). **Fig.(8.3a).**



Production Rate Vs. Process Time Ratio(See-Saw). **Fig.(8.3b).**



Production Rate Vs. Process Time Ratio(3-Stage Bowl). **Fig.(8.3c).**



Production Rate Vs. Process Time Ratio(4-Stage Bowl). **Fig.(8.3d).**

Effect of Processing Time Variability On Production Rate

Each unbalancing method was an associated production rate Vs. processing time ratio (PTR) graph pattern. As the variance is increased, so too is the distortion to the production rate pattern, the actual maximum output value however is reduced.

The three and four stage bowl unbalancing methods produce smaller ranges of production rate than either of the other two unbalancing methods at all variance values. The ranges produced however are concentrated at higher levels of output values.

Cantilever Case

For each of the three variance values while the system is approaching balance (all stations with $\mu=15$), the production rate, tends to oscillate around that which is achieved when the system is balanced. As the processing times begin to increase above the balanced configuration, the production rate, decreases in an almost linear fashion. Fig. (8.3a).

The greatest output is achieved in all three cases before the system reaches balance, (PTR=1) but not necesarily when the actual cumulative processsing is minimal. With a variance of 1, the maximum production rate achieved is 31 units, one above that achieved at balance. This value is achieved when the processing time ratio (the ratio of the processing time at an imbalanced station to that at a balanced on is .73.

See Saw

For each variance value as the processing time of the first stations are increased towards balance the output of the system also increases. With the small variance value, the maximum output of the system coincides with the balanced case, however, with the higher variance values this maximum value occurs just past the balanced configuration. Once the maximum system output is achieved, further increases in processing time ratio, causes the production rate to decrease. Fig. (8.3b). The maximum system output is achieved with the smallest variance value. It coincides with that achieved while in the balanced configuration (30 units).

3 Stage Bowl

In this case a graph of production rate Vs. PTR produces an interesting step type graph, although this is distorted slightly with the higher values of σ. In all three cases output, decreases as balance is approached, but maximum values are attained when the PTR values are very small (0.33 - 0.47). As the system moves away from its balanced position production rates continue to decrease, although, with the higher variance values, this trend fluctuates slightly. Fig. (8.3c). The small variance value again produces the greatest production output. - 32 units, which is two units above the balanced configuration.

4 Stage Bowl

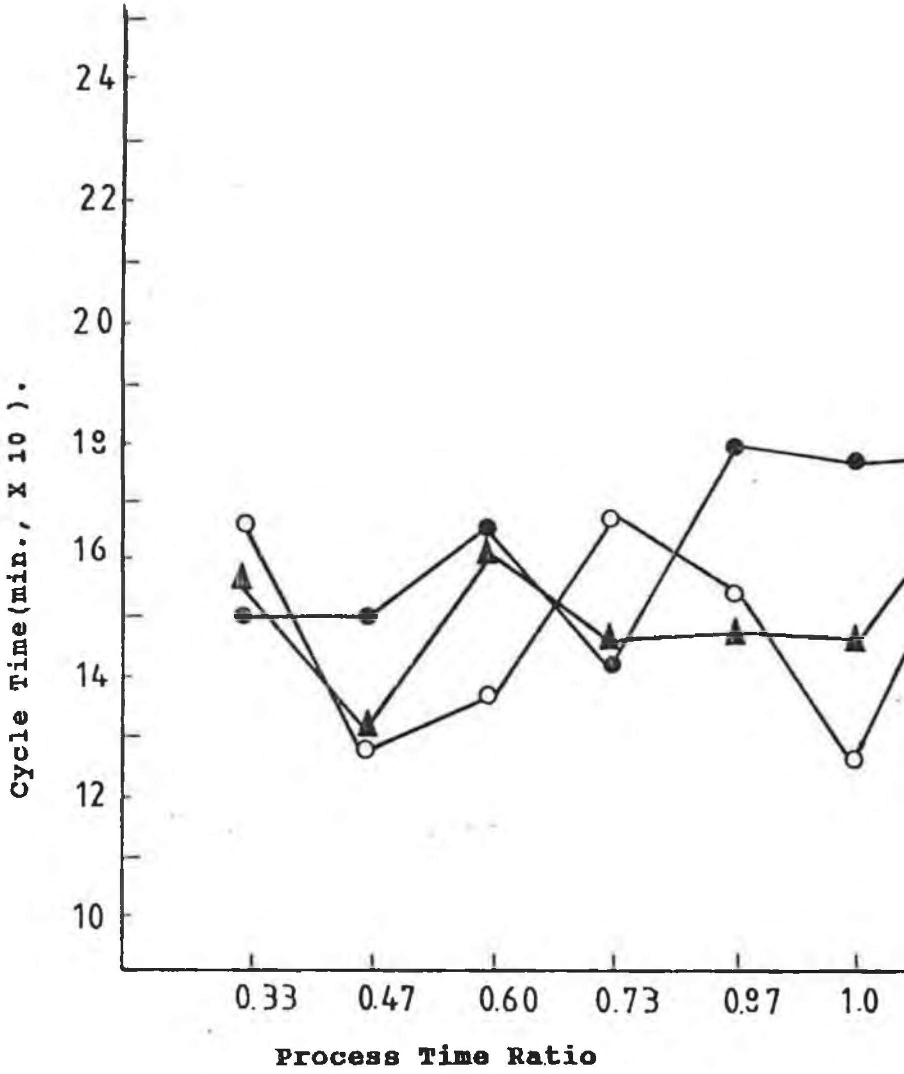
The graphs presented for this configuration bear considerable resemblance to those produced by that of the 3 Stage Bowl. As the system configuration tends towards balance, (and the processing times of the 2nd 3rd stations increase), the output reduces, although as the variance increases, slight fluctuations occur. With the small to medium variance values, maximum output values occur when stations 2 and 3 have small PTR values, with the higher variance value however, the maximum output is again reached just before balance (Fig. 8.3d).

Effect of Processing Time Variability On Cycle Time

It would appear from the cycle time graphs that when utilizing either a see-saw or cantilever configuration, the actual variance values achieved do not produce large changes in cycle times. Using a bowl configuration however, the actual variance values effect on cycle times are much more marked.

Cantilever

At low values of process time ratio, the cycle times of each of the variance values, are concentrated within a specific area, and show similar trends. As the system approaches balance however the cycle times at the different values tend to separate, with the largest variance value exhibiting the longest cycle time and the smallest variance value the shortest cycle time. As the system moves away from the balanced



Overall Cycle Time(Cantilever).

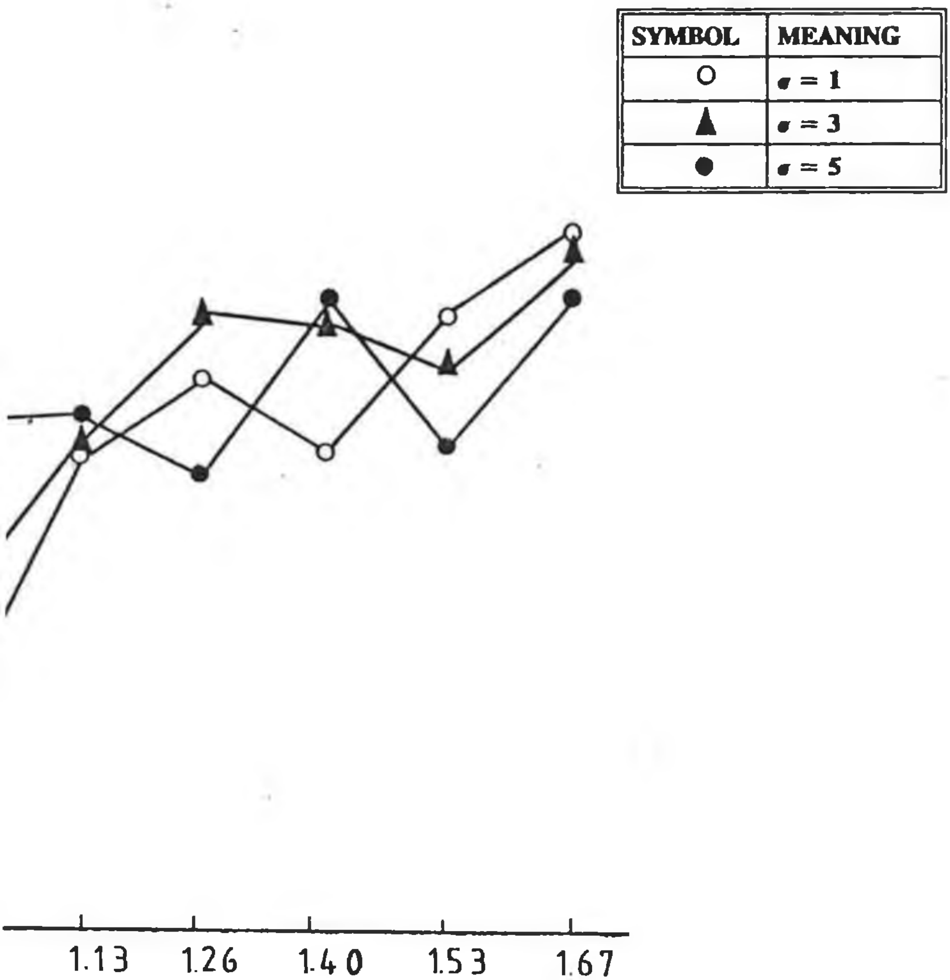
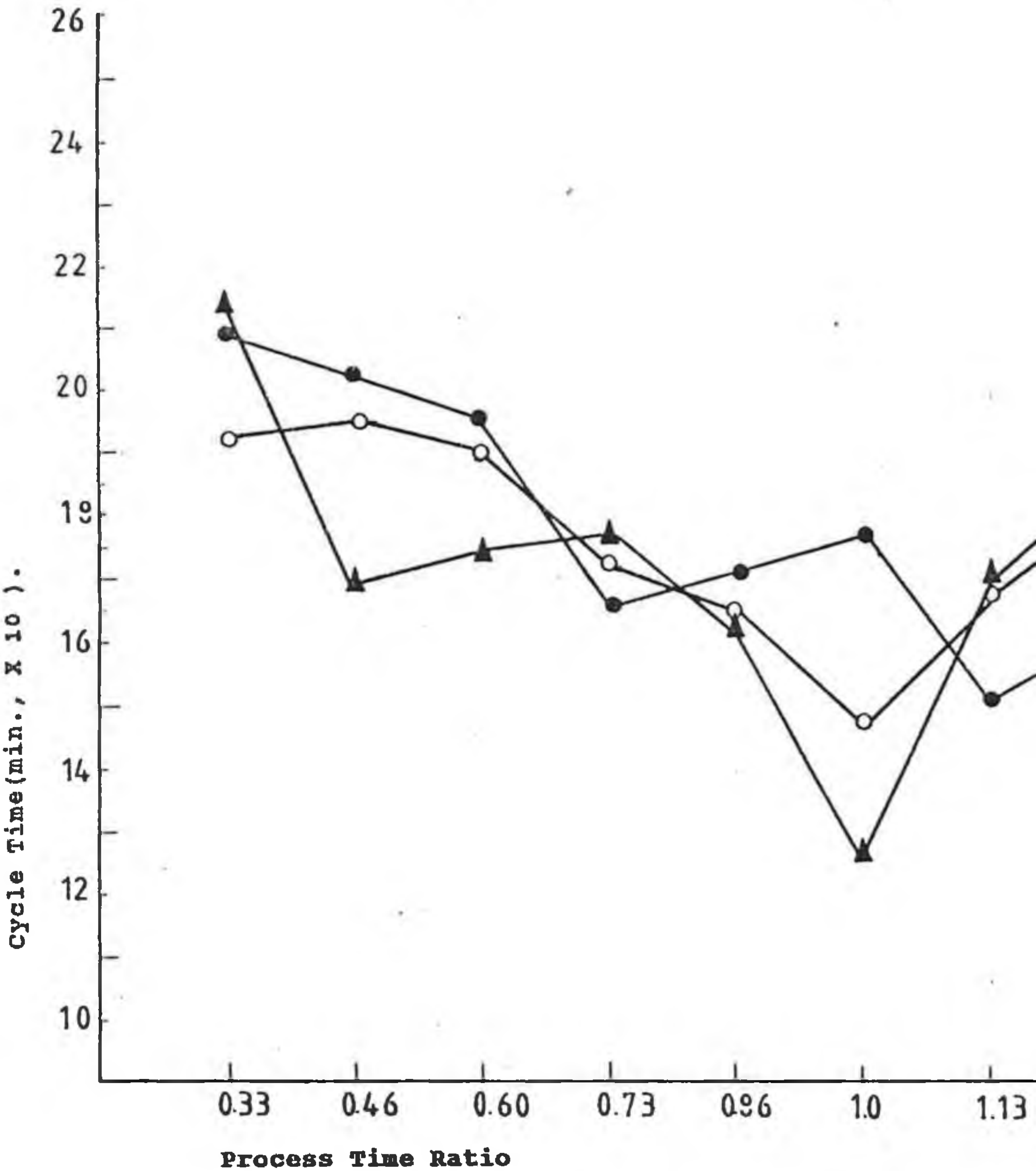
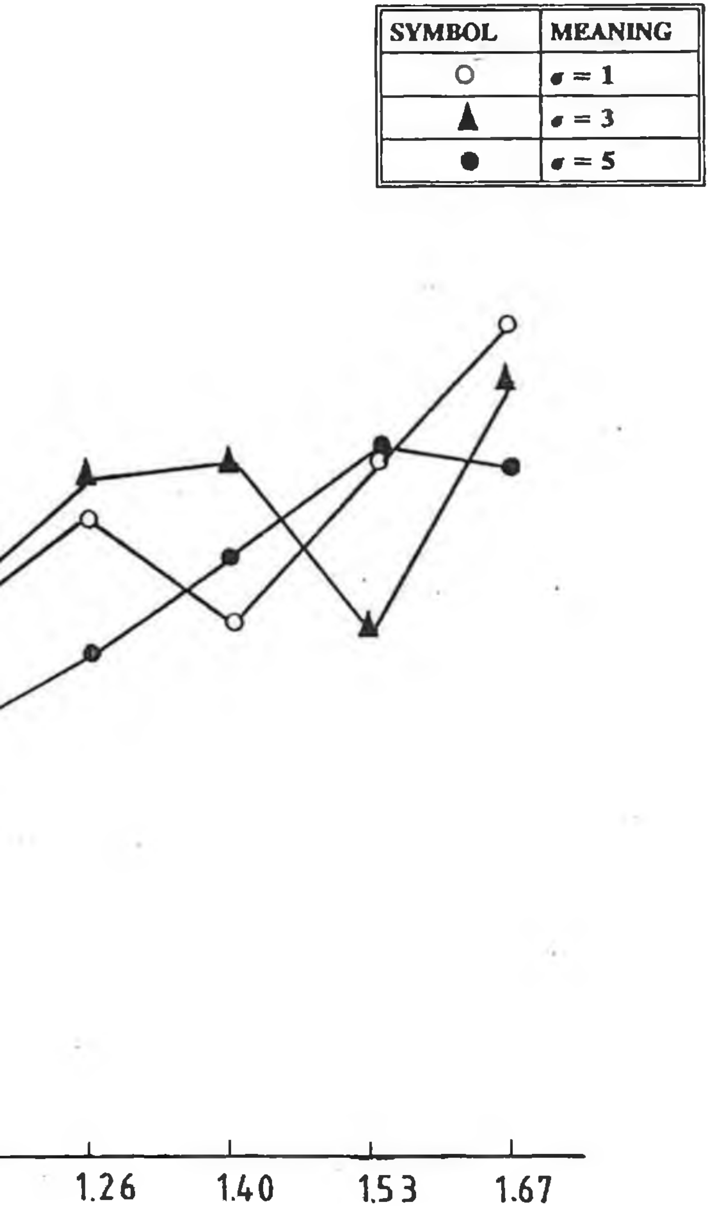
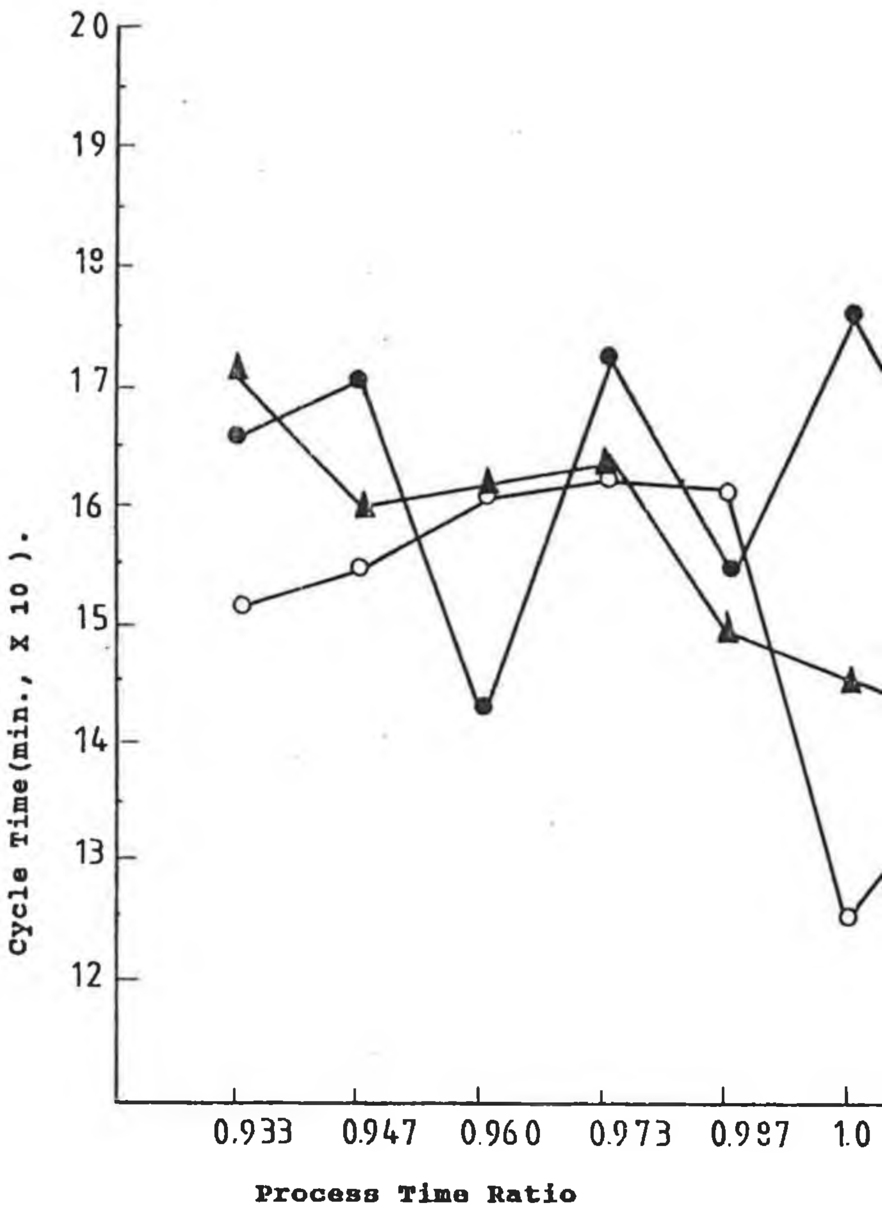


Fig.(8.4a).


26
24
22
20
18
16
14
12
10
Cycle Time(min., x 10).
0.33
0.46
0.60
0.73
0.86
1.0
1.13
Process Time Ratio


SYMBOL
MEANING
σ = 1
σ = 3
σ = 5
1.26
1.40
1.53
1.67



Overall Cycle Time(3-Stage Bowl).

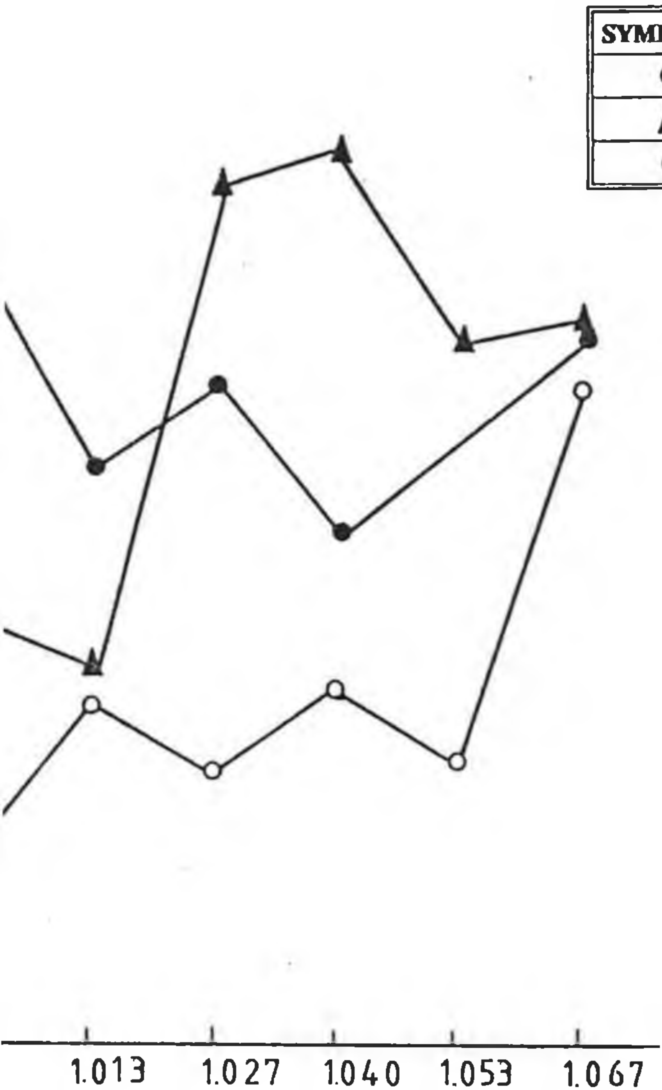
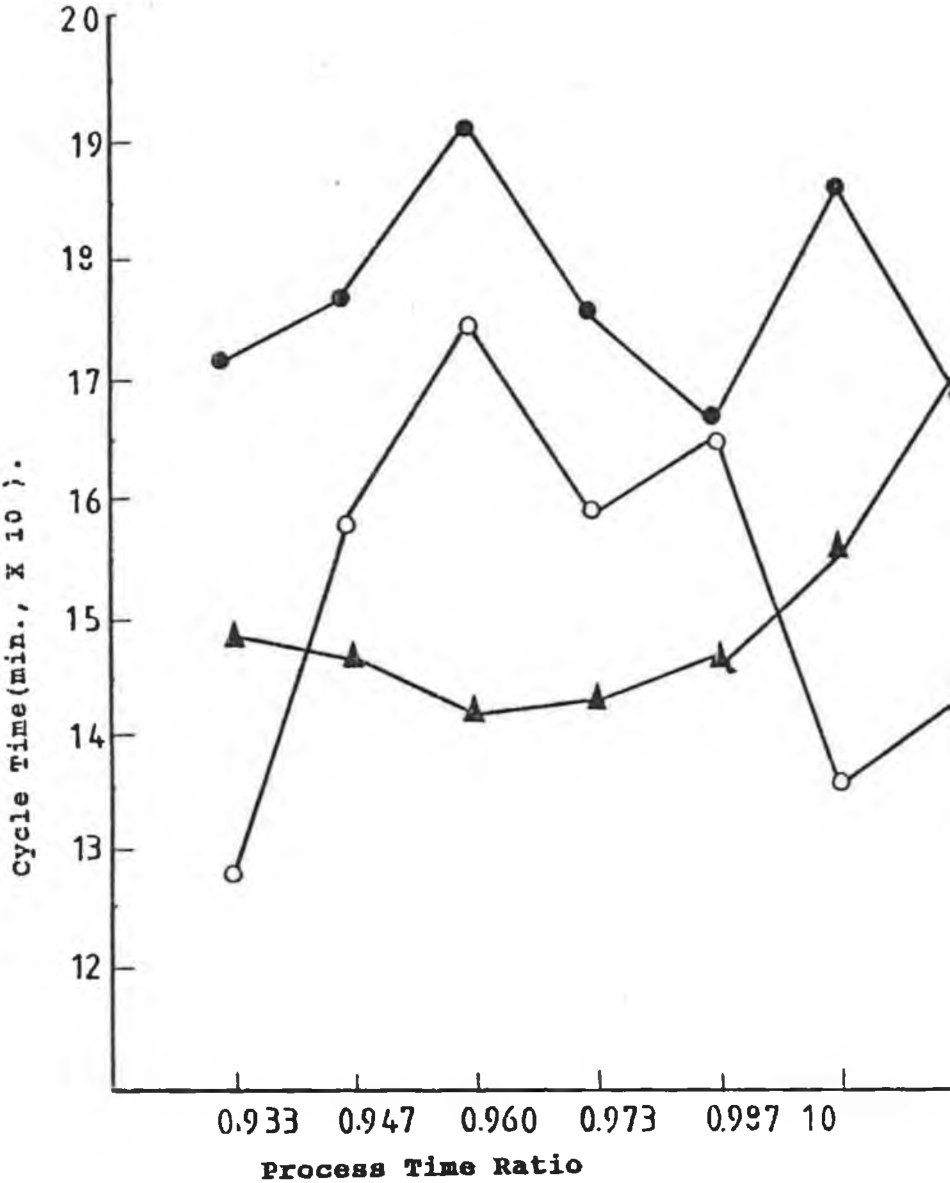


Fig.(8.4c).



Overall Cycle Time(4-Stage Bowl).

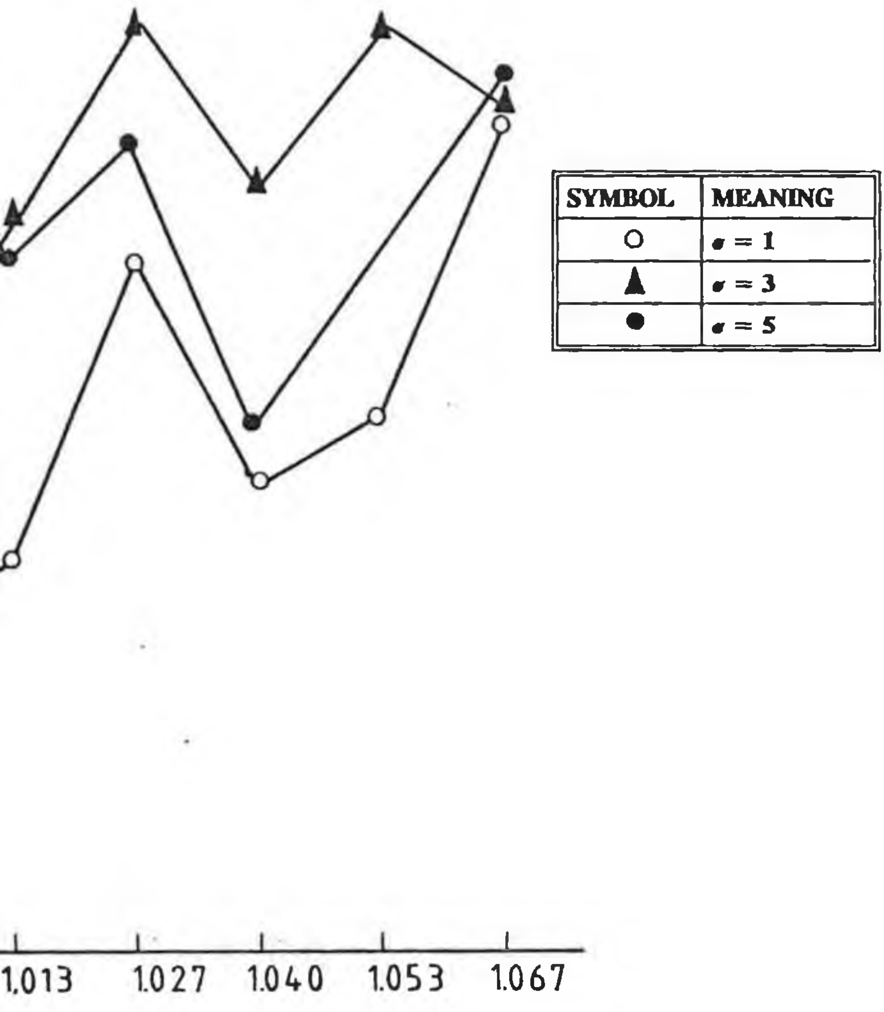


Fig.(8.5d).

configuration, the cycle times of all three variance values tend to concentrate in a similar region agin (Fig. 8.4a).

The general trend of this cycle time graph is upwards and increasing, although the slope is not as great at lower values of process time ratio. This is fairly consistent with the production rate graph, which it exhibits fairly constant output rates up to balance, however as the cycle times increase, production rates drop. The minimum cycle time obtained with a variance of 1 is 126 minutes, which is achieved at balance.

<u>See Saw</u>

With low values of process time values. The cycle times of the variance values intermingle and are concentrated in a similar region. However as the balanced configuration is approached, the cycle times of the three variance values separate. Moving away from balance however the three variance values again become entwined.

The general trend of the graph is concave, which is fairly consistent with that of the production rate, which is convex, over the same x axis range. The trend of the graph would seem to imply that with the see saw configuration, it is the cumulative processing time along the line which determines the cycle time, rather than the way in which the time is distributed. (Fig. 8.4b).

The maximum cycle time is obtained with the smallest variance (126 minutes) however the range of cycle times obtained is the largest of the three variance values investigated.

<u>3 Stage Bowl</u>

Here the three variance values do not exhibit similar trends. At low values of process time ratio, the three variances exhibit cycle time values which are relatively far apart. This may be accounted for by considering the greater range of production rate achieved across the spectrum of variances at the lower end of the process time ratio scale, in comparison to the previous system configurations. As the configuration approaches balance, the three variances begin to converge slightly, but diverge markedly to pass through the balanced state. Once apart, the variances remain apart, - with the two lower values σ_1, and σ_3 exhibiting similar trends-, until the end, when all three variances converge to a similar range. (Fig. 8.4c).

The graph demonstrates that when the bowl is convex, ie. lower processing times assigned to work stations 1 and 3, the effect of an increase in variance is not as marked as that seen when the bowl is concave. The general trend of the graph is linear in keeping with the small range of production rate.

The mimimum cycle time (126 min) is achieved with the lowest variance value, and interestingly does not correspond to maximum thruput. This value is achieved at balance.

4 Stage Bowl

The four stage bowl cycle time graph, is similar to that of the three stage one. At small values of PTR, the three variances show cycle time values which are very far apart, again accounting for the large range of production rates at similar process time values. It is interesting to see however that unlike the other three graphs, these three graphs don't begin to converge until after the balanced configuration has been passed through. At the final process time ratio, all three variance values produce cycle times which are the closest exhibited at this ratio in any of the previous graphs (Fig. 8.4d).

In processing time terms the four stage bowl does not really become bowl shaped until the processing times at work stations 2, 3 rise above the balanced value. Comparing this graph to that of the 3 stage bowl, it is evident that since processing times have achieved convexity, the actual number of work stations over which the bowl occurs is of little importance, with the variance values in both graphs exhibiting similar trends.

The minimum cycle is (118 min) achieved with the lowest variance value (6.1), and does not occur at balance, but with a processing time ratio of 0.93.

Effect Of Processing Time Variability On Individual Queue Length

Each unbalancing method also has an associated queue length pattern. Varying the processing time at any one work station, in the line, not only effects that station but also all the other stations in that line.

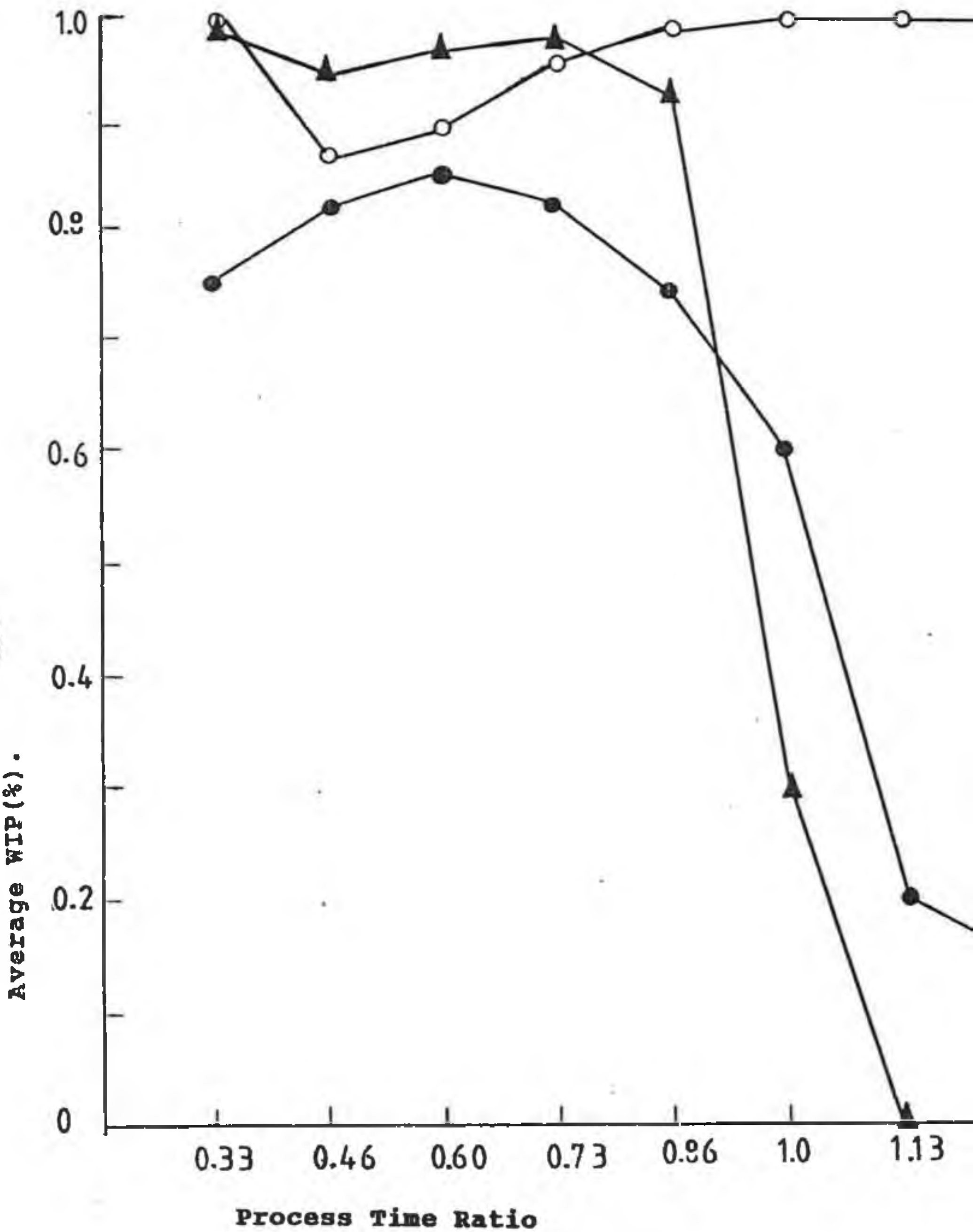
Both the see-saw, and cantilever graphs demonstrate that for processing time ratios less than balance, the introduction of higher variance values tends to bring the queue lengths closer together.

The bowl graphs show that the introduction of the higher variance values both increases the queue lengths and brings them closer together across the range of processing time ratio, irrespective of whether it is concave or convex it may be said therefore that the effect of variance on the bowl configurations are much more marked.

Each of the assembly feeder lines are simultaneously varied by the same amount. It is therefore feasible, when investigating the performance of individual work stations to take one feeder line, and assume its work stations performance to be indicative of the corresponding work station on another line.

Cantilever

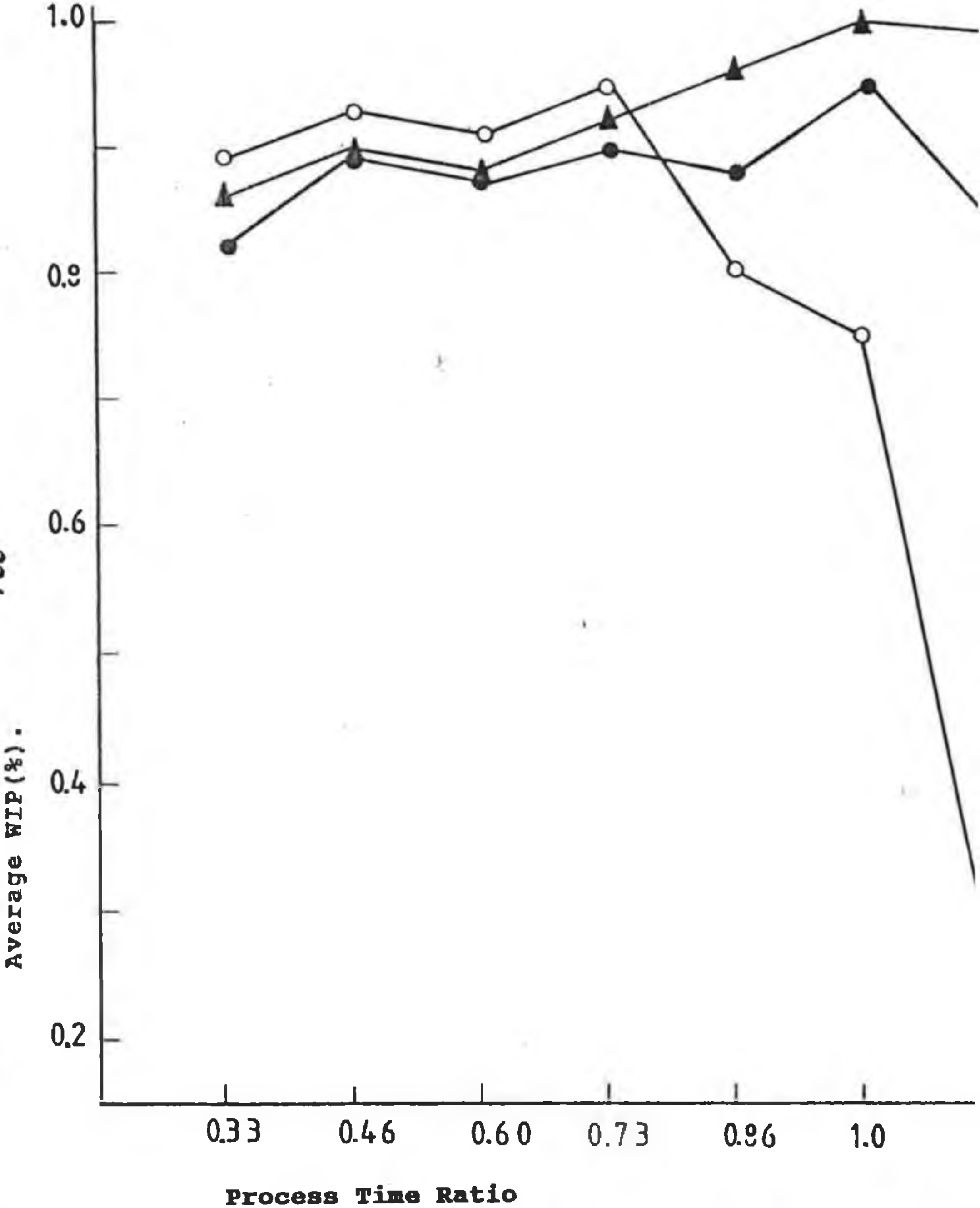
The cantilever configuration, graphs of process time ratio against queue length demonstrates that each station within a feeder line behaves very differently. The first work station in the line, -the work station at which process times are varied has a fairly constant queue length, especially after balance has been achieved. The second and third stations demonstrate quite a varied queue length (Fig. 8.5a).



Individual Average WIP levels(Cantilever,σ = 1).

SYMBOL
MEANING
WORKSTATION 1
WORKSTATION 2
WORKSTATION 3
1.26
1.40
1.53
1.67

Fig.(8.5a1).



Individual Average WIP levels(Cantilever c = 5)

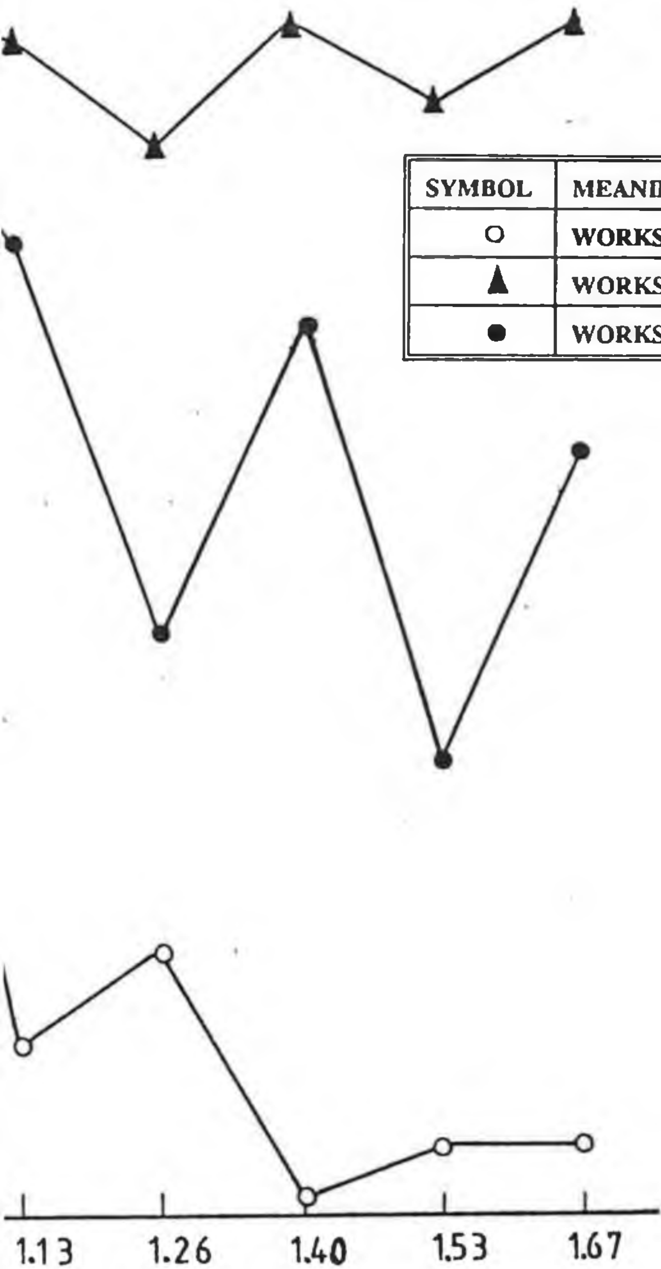
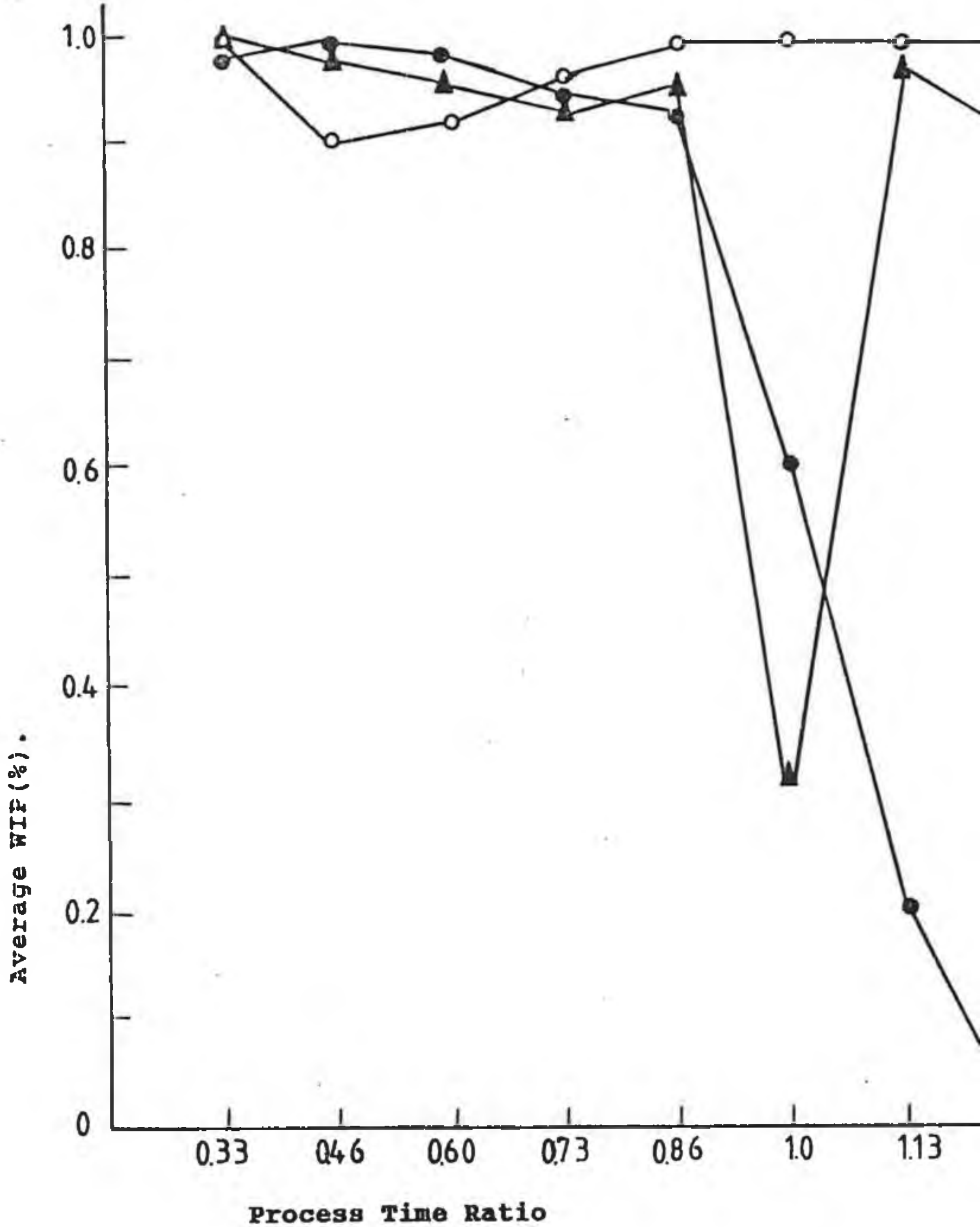
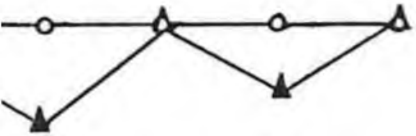

SYMBOL
MEANING
WORKSTATION 1
WORKSTATION 2
WORKSTATION 3
1.13
1.26
1.40
1.53
1.67

Fig.(8.5a2).



Individual Average WIP levels(See-Saw,σ = 1).



SYMBOL	MEANING
O	WORKSTATION 1
▲	WORKSTATION 2
●	WORKSTATION 3

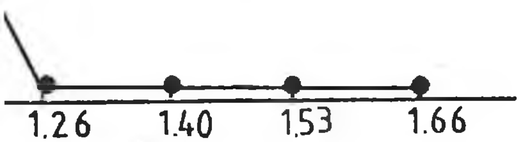
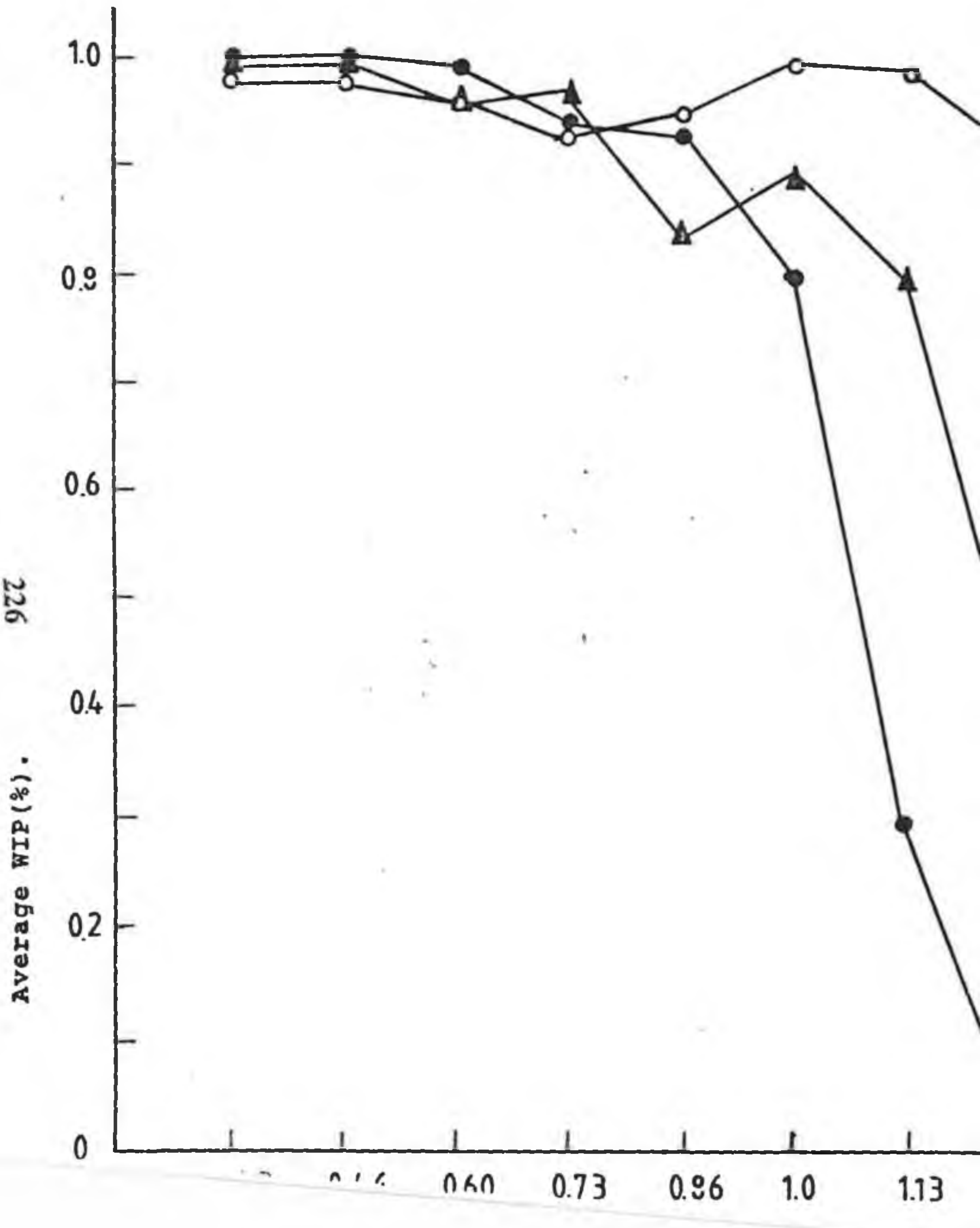
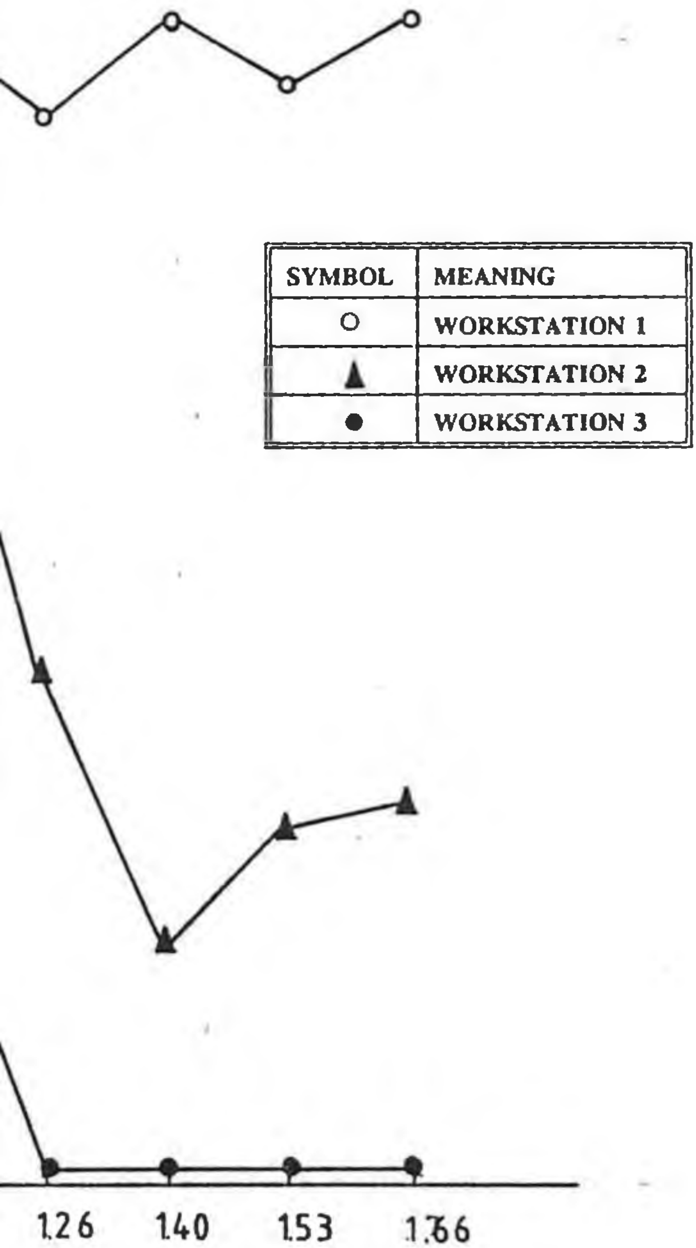
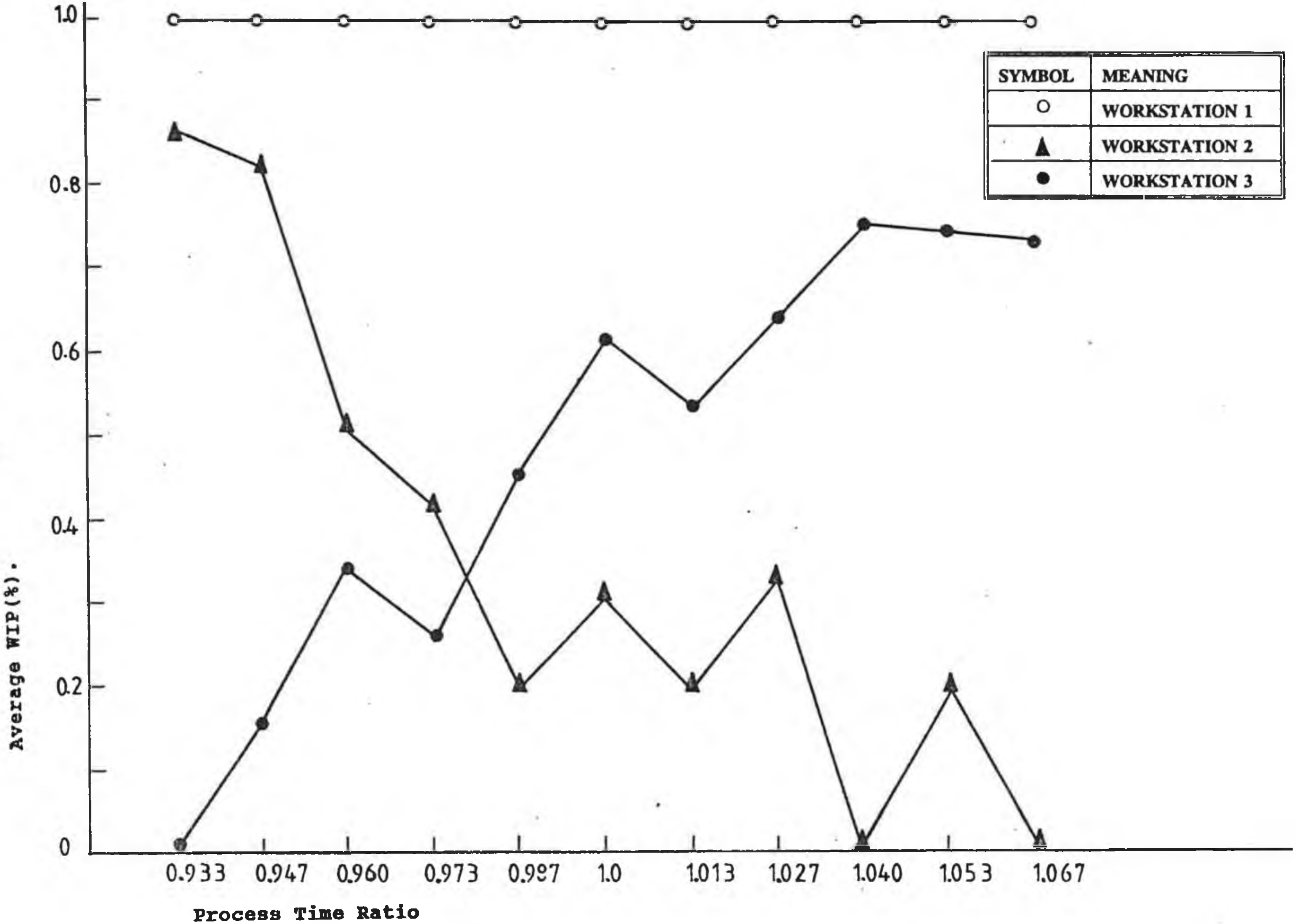


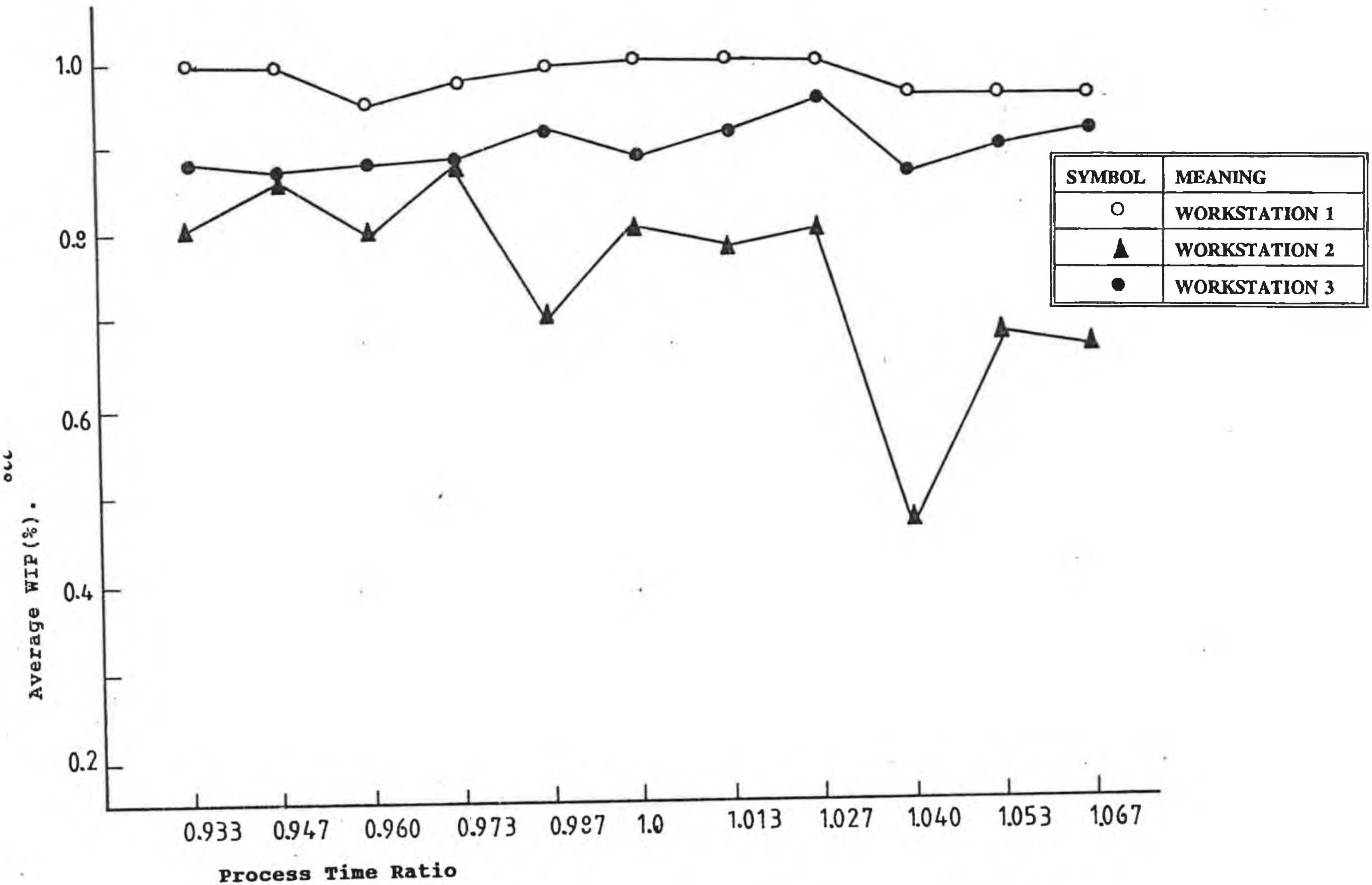
Fig.(8.5b1).


1.0
0.8
0.6
0.4
0.2
0
Average WIP(%).
0.60
0.73
0.86
1.0
1.13

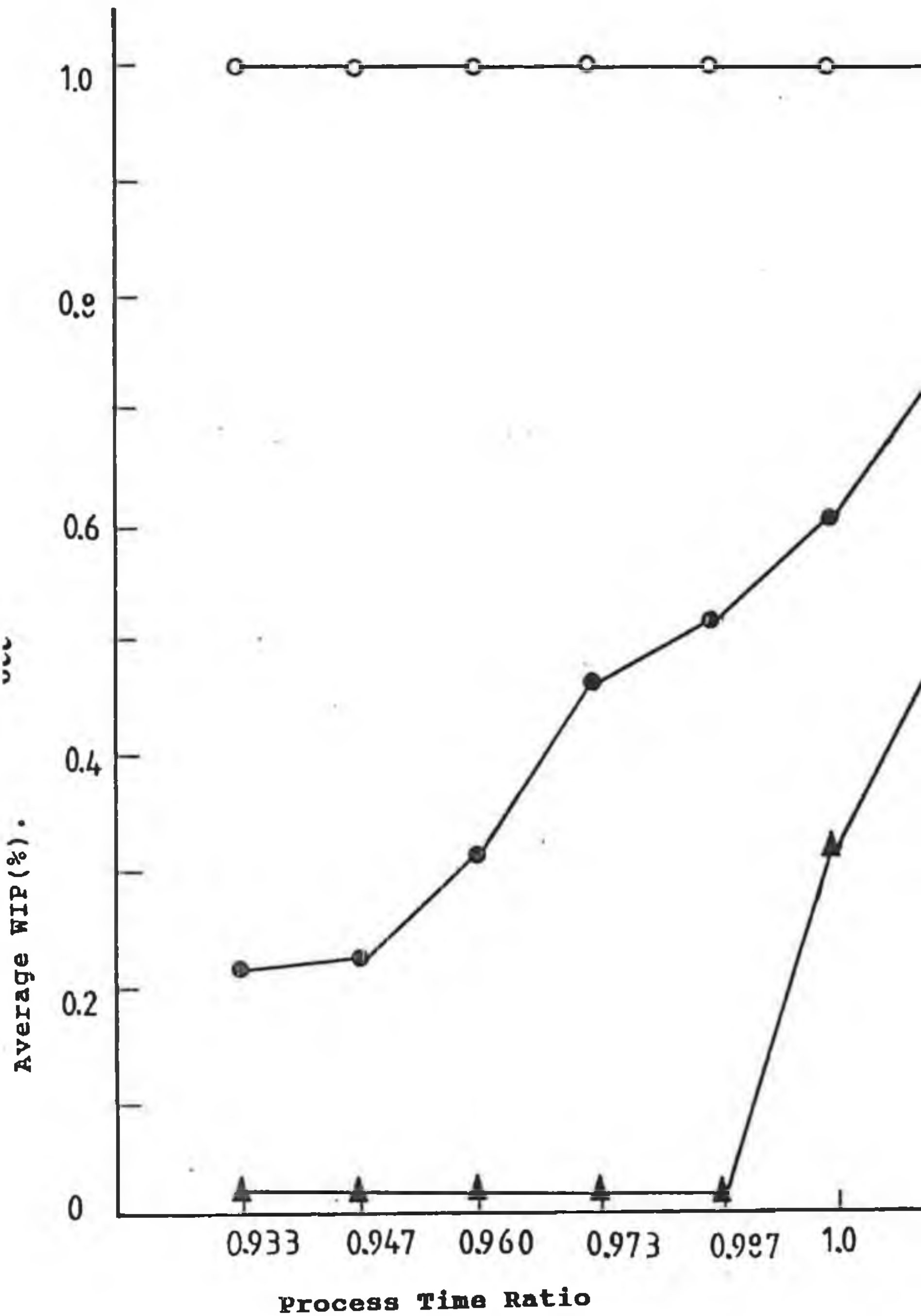

SYMBOL
MEANING
WORKSTATION 1
WORKSTATION 2
WORKSTATION 3
1.26
1.40
1.53
1.766

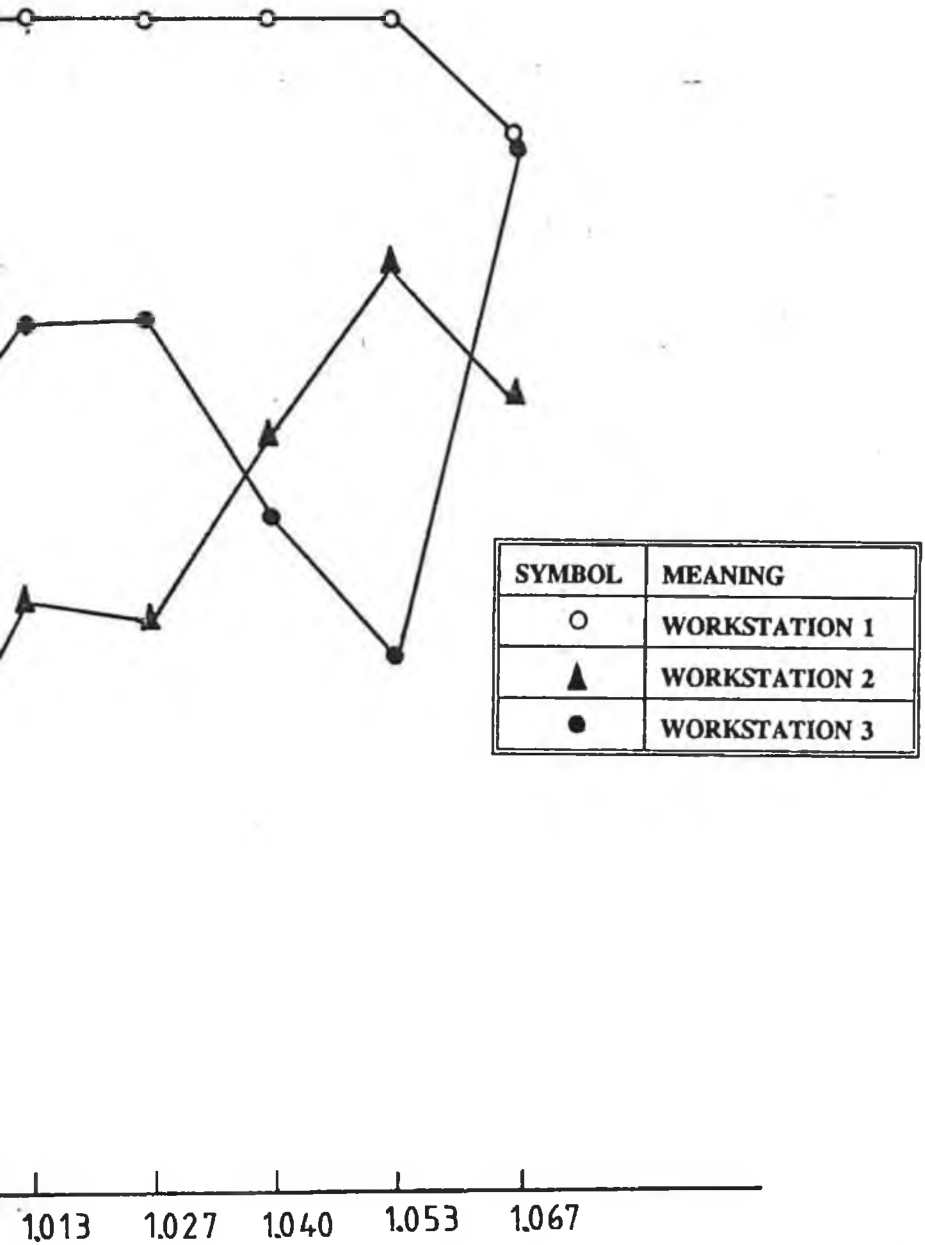


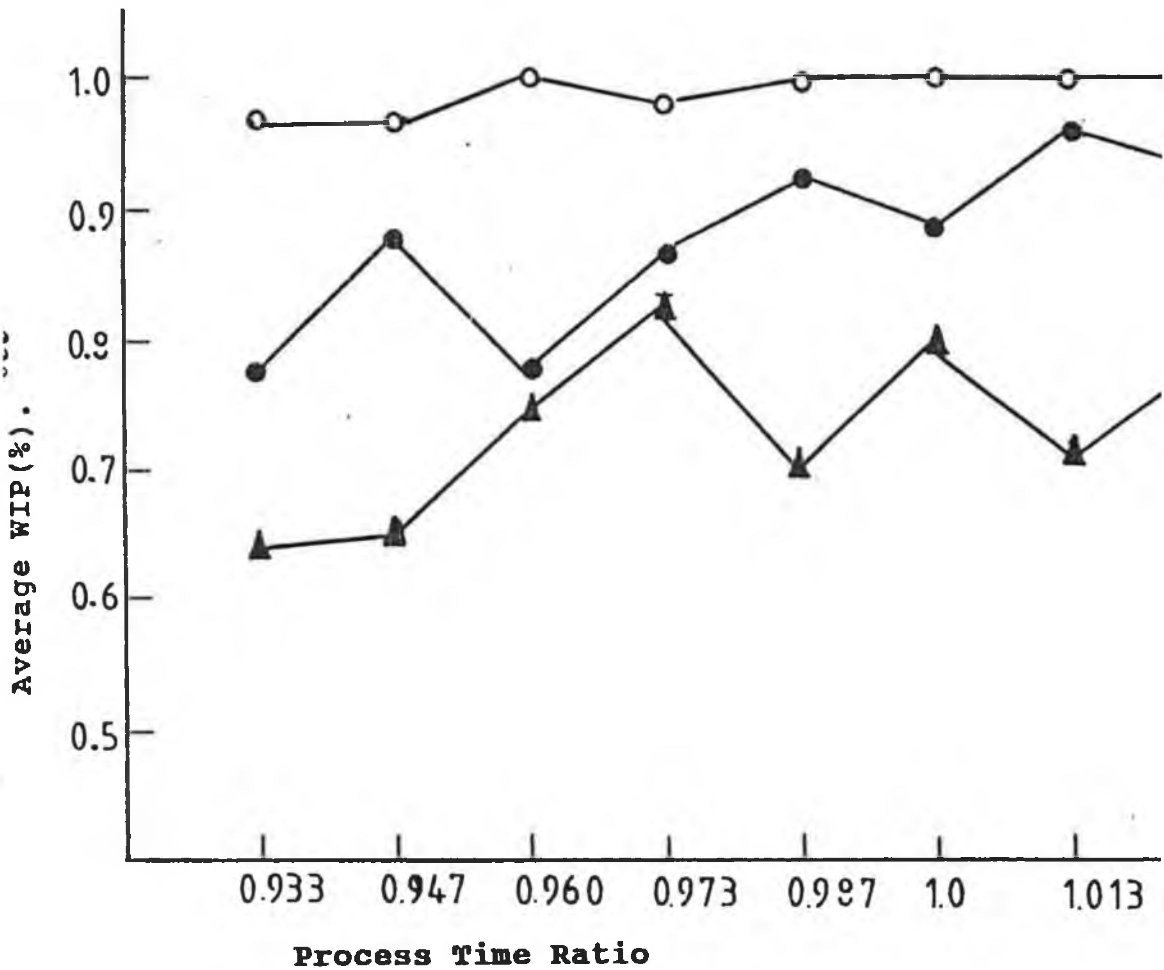
Individual Average WIP levels(3-Stage Bowl,σ = 1). **Fig.(8.5c1).**



Individual Average WIP levels(3-Stage Bowl, $\sigma = 5$). Fig.(8.5c2).


1.0
0.8
0.6
0.4
0.2
0
Average WIP(%).
0.933
0.947
0.960
0.973
0.987
1.0
Process Time Ratio


SYMBOL
MEANING
WORKSTATION 1
WORKSTATION 2
WORKSTATION 3
1.013
1.027
1.040
1.053
1.067



Individual Average WIP levels(4-Stage Bowl,σ = 5).

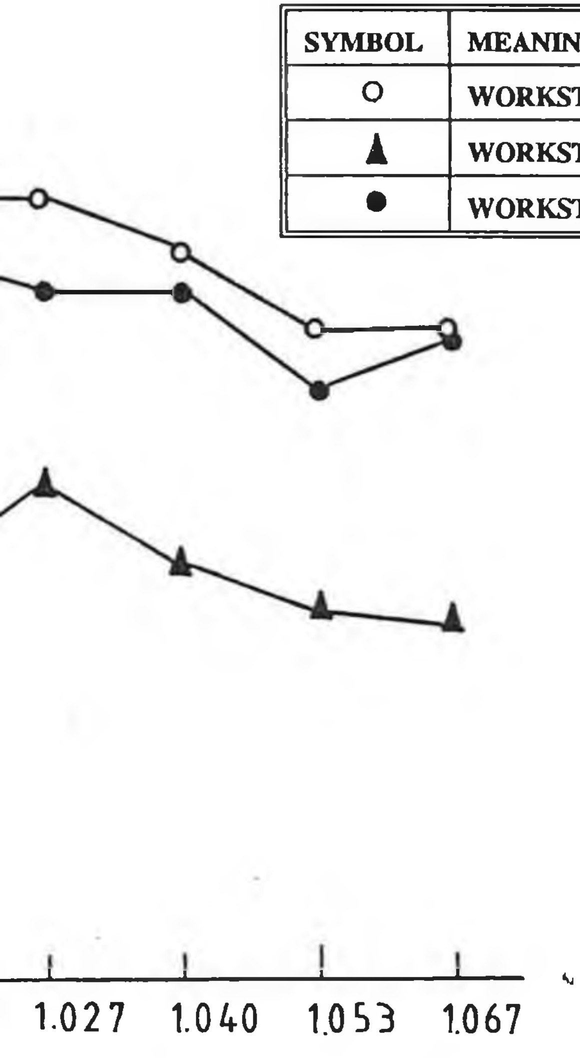

SYMBOL
MEANING
WORKSTATION 1
WORKSTATION 2
WORKSTATION 3
1.027
1.040
1.053
1.067

Fig.(8.5d2).

As the variance value increases, the difference in queue lengths before balance are much less marked, and in fact the respective lengths are much higher at balance. On passing through the balanced state, it takes a much greater difference in processing time to reduce the second station's queue length to zero. The increased variance effects the third work station the most, preventing it from being reduced to zero.

See Saw

At low values of processing time ratio, the queue lengths of each of the three stations are relatively high and tend to follow processing times. The first station, with the shortest processing time has the shortest queue length, and the third station with the longest processing time has the longest queue length. Once the system configuration has passed through balance, the second work station regains its previous queue length, and the queue length at the third station, -which now has the shortest processing time, -fades away to zero. The first station now has the longest queue length (Figs. 8.5b1, 8.5b2).

The introduction of the higher variance value, tends to draw the queue lengths of the three stations closer together at lower processing time ratios. Once balance has been achieved however, the length of the queue at the second and third work station fade away towards zero.

3 Stage Bowl

The bowl configuration produces a much greater range in queue lengths than seen in either of the previous systems. Irrespective of whether the bowl is concave or convex, the first station retains the longest queue length. The second station which has the longest processing time before balance decreases as the bowl becomes more convex. While this is happening, the queue at the third station which has a shorter processing time than work station 2 increases in length, and in fact becomes longer than that at work station 2 before balance is reached. (Figs. 8.5c1, 8.5c2).

With a concave bowl, the second station, which now has the shortest processing time also has the shortest queue length, and the third station, the longer queue length. The concave bowl structure however produces a much smaller range in queue lengths at individual stations than with the convex structure.

The introduction of the higher variance value, has two noticable effects. Firstly it brings the queue lengths of stations 2 and 3 much closer together, and reduces the difference in values obtained with both the concave and convex structure. Secondly it increases the queue lengths at both stations to much higher values than that achieved at low variance values. The effect of variance on the first station is much less marked.

4 Stage Bowl

The so called 4 stage bowl, effects the first work station in each line in a similar fashion as the 3 stage bowl, producing a fairly constant queue length of one. The graphs of the second and third work station queue lengths however are quite different. With the concave bowl, the second work station has no queue over a large range of processing times, while the queue length at work station three is very small but increasing. Once a queue appears at work station two, both queues continue to increase in parallel, through the balanced configuration. With the convex structure however the queue length at work station 3 suddenly drops off, and is overtaken by the queue at work station 2. (Figs. 8.5d1, 8.5d2).

The introduction of the higher variance value, has a similar effect to that exhibited with the three stage bowl, in that it raises the overall queue length at stations 2 and 3, across the range processing time ratio, and brings the queues much closer together.

Effect of Processing Time Variability on Individual Resource Utilisation

The individual resource utilization graph, demonstrates the variation in, the percentage of overall shift time that a particular resource spend in use, as the processing time ratio increases.

The see-saw and cantilever configurations demonstrate a distinct tendency at each work station for utilization values to follow WIP levels at that station. The two bowl like configurations however would appear to allow the stations to take their respective utilization values from their postions in the feeder line.

Cantilever

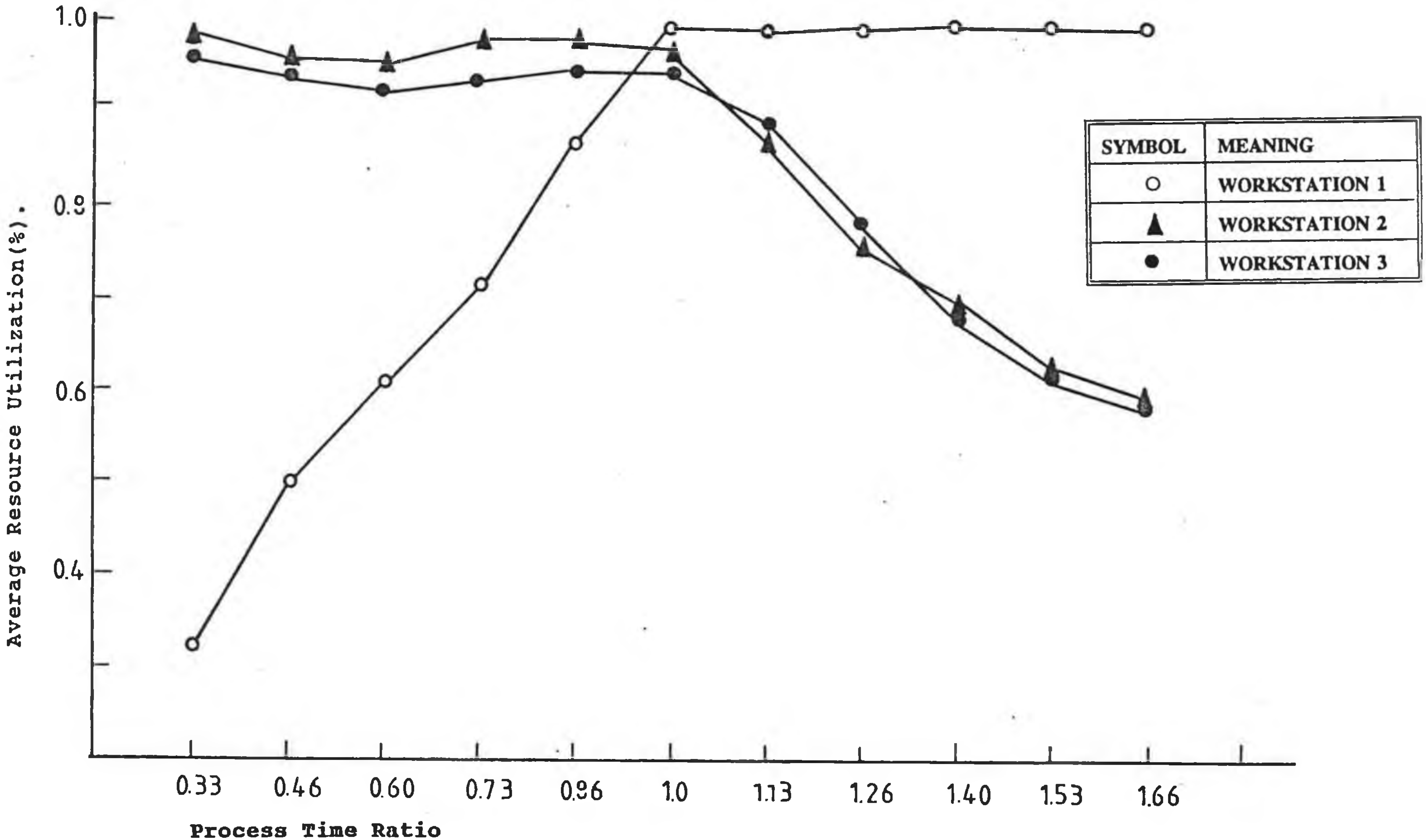
The graph shows that with the cantilever configuration, resource utilization is fairly linear, both before and after balance. When the processing time at work station one is relatively low, as so to is the level of inventory in the input buffer, the actual resource utilization is also low. However as the processing time increases so to does the utilization and input inventory level. Work stations two and three, with similar processing time and higher levels of inventory in their buffers, have higher utilization values, although once the balanced configuration is achieved, and their inventory levels drop, due to longer processing times at work station one. Their utilization levels drop fairly linearly with the increase in processing time, while the first work station remains at maximum utilization.

An increase in the variance value does not redefine the shape of the graph. It does shift the points at which the first station achieves maximum utilization, and the utilization values of work stations two and three to the right, which means that they now occur at higher processing time ratios. This effect echoes that which is exhibited in the queue length graphs. (Figs 8.5a1, 8.5a2).

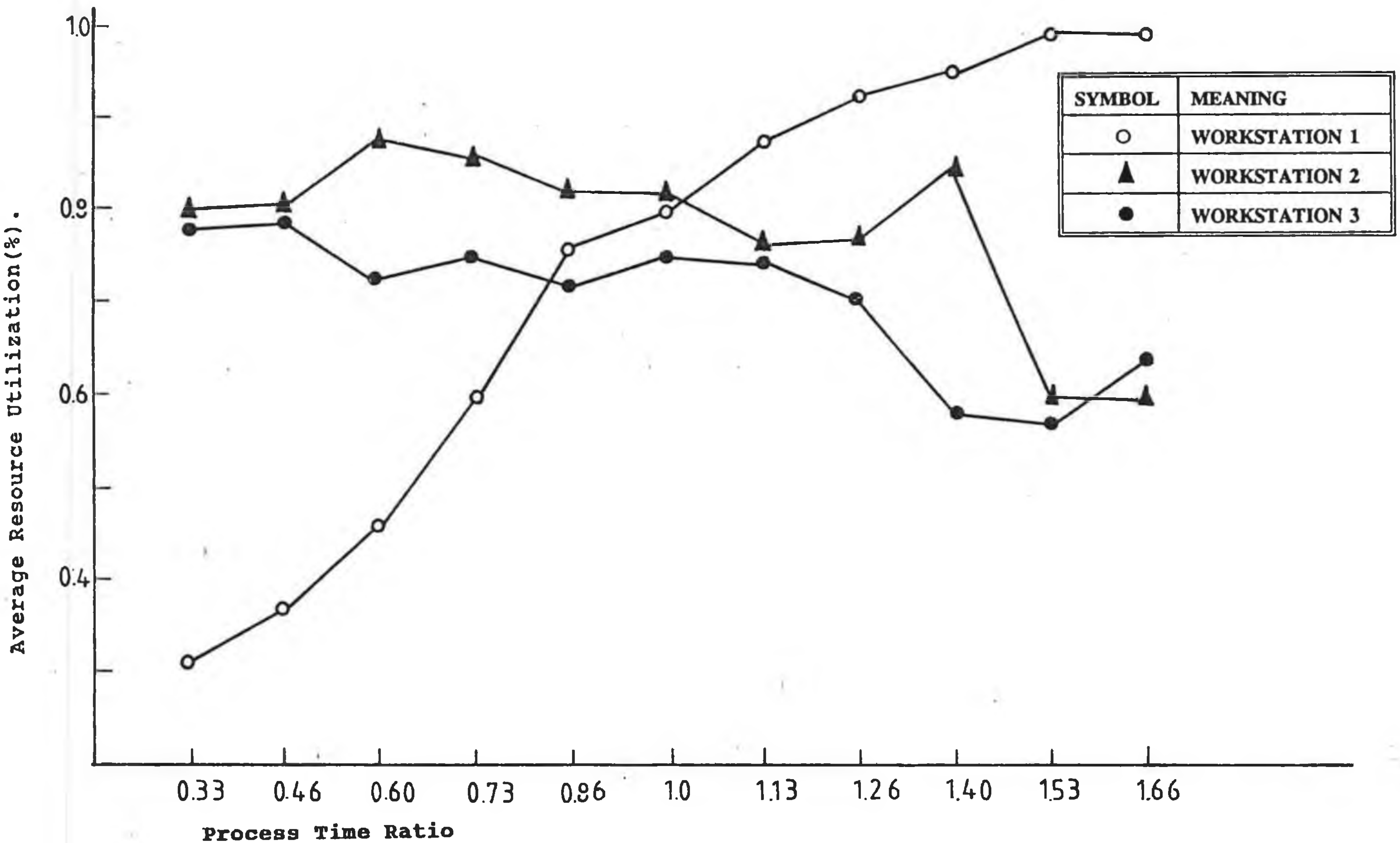
See Saw

The utilization graphs of the see saw configuration are also fairly linear about the balanced state.

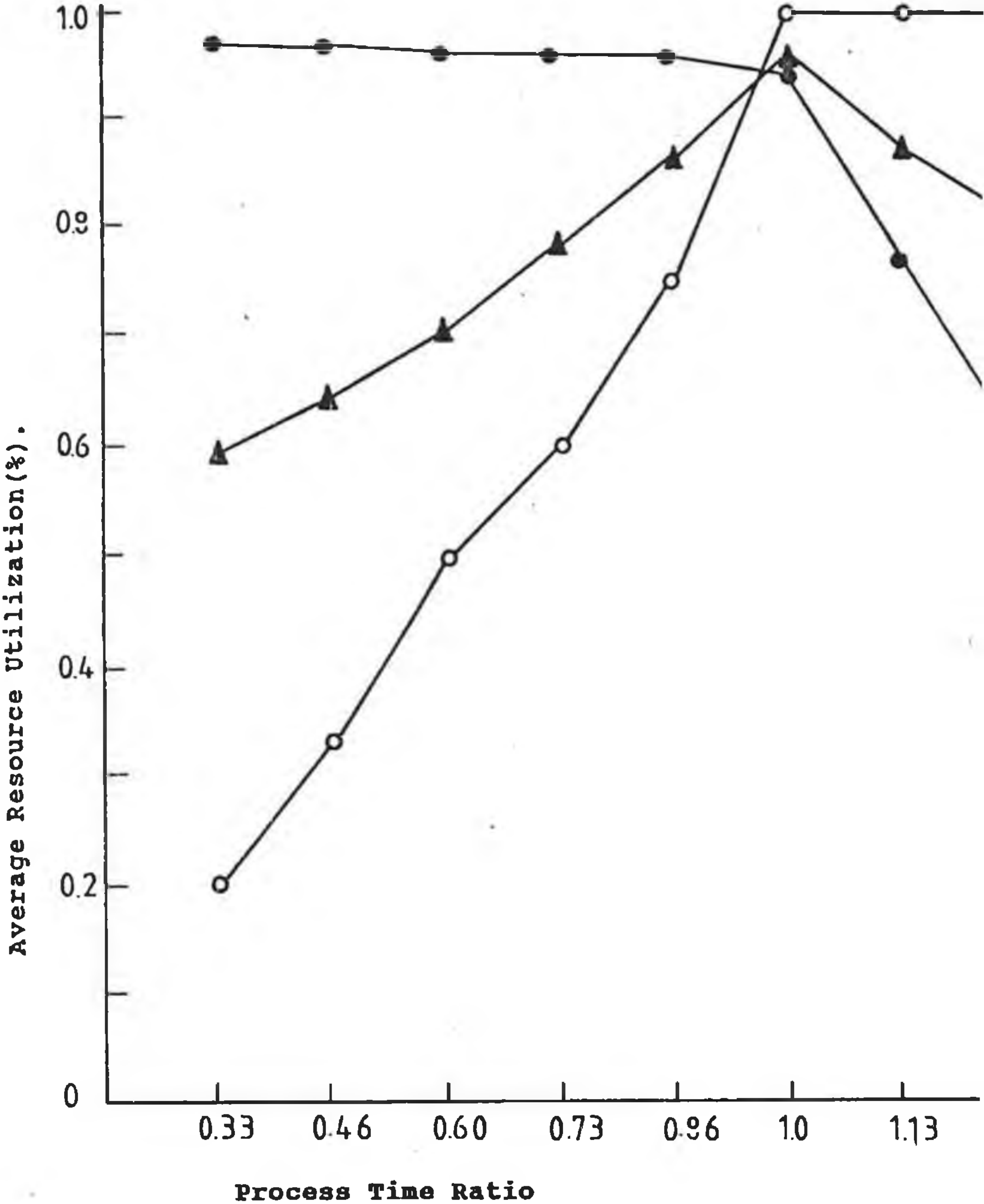
The first and third stations show a similar pattern to that exhibited in the cantilever case, with the first station increasing to maximum utilization as the processing time increases, and the third station decreasing in a similar fashion. The graph shows



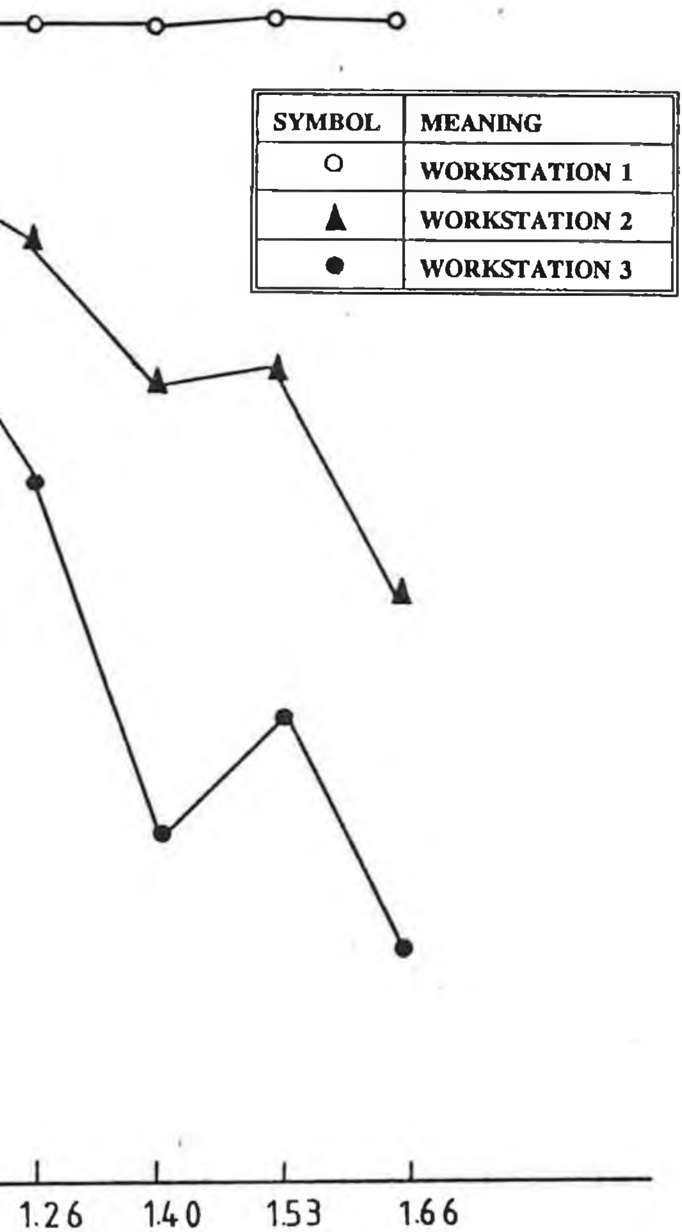
Individual Average Resource Utilization(Cantilever,σ = 1). **Fig.(8.6a1).**



Individual Average Resource Utilization(Cantilever,σ = 5). **Fig.(8.6a2).**

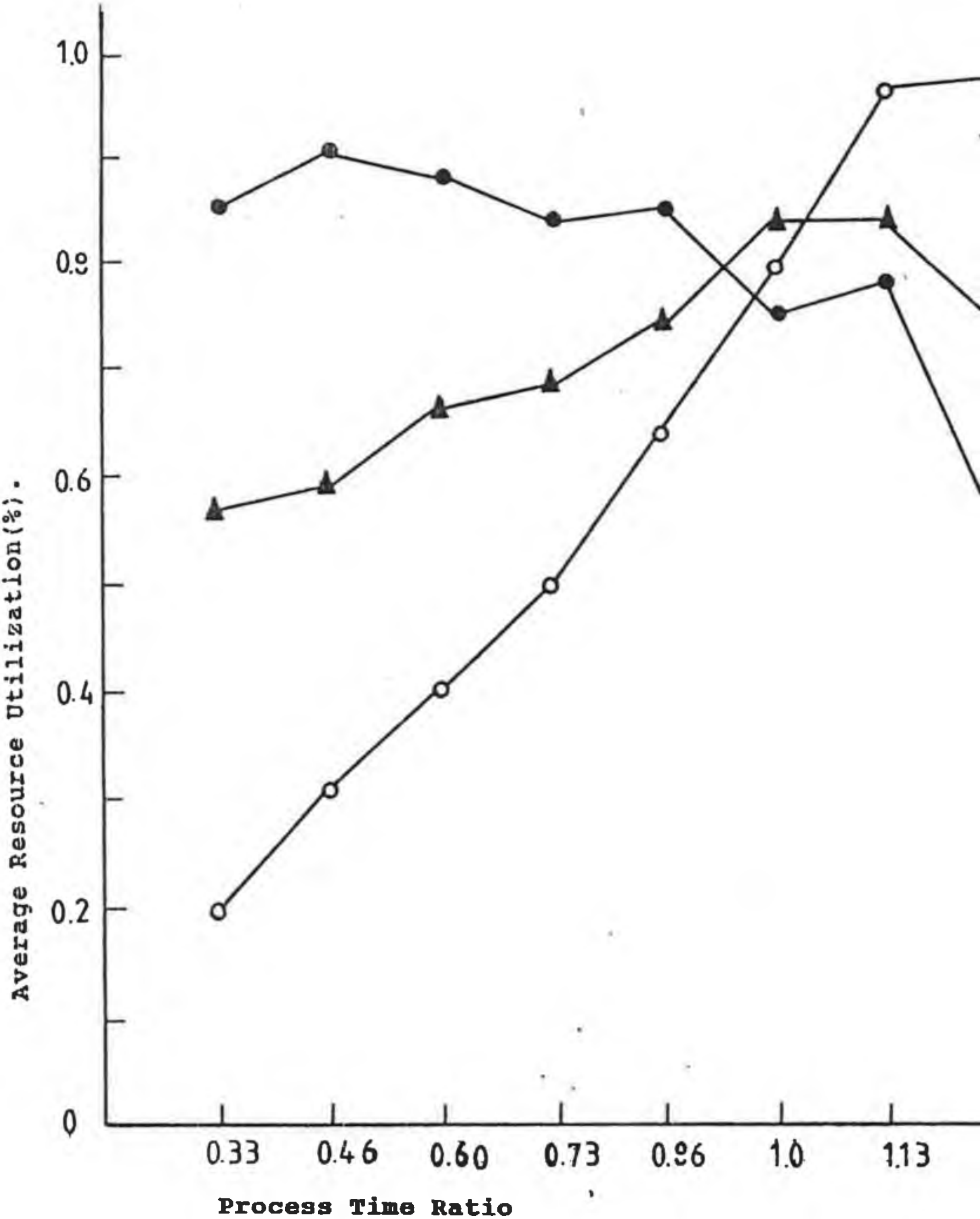


Individual Average Resource Utilization(See-Saw,σ =

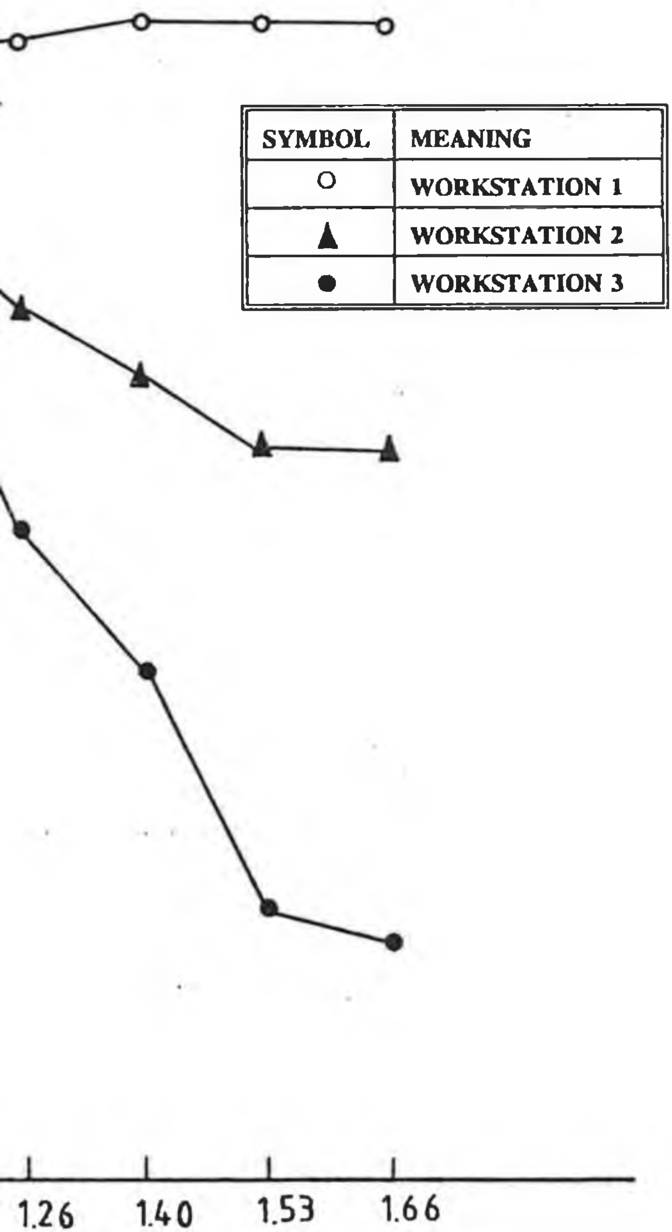

SYMBOL
MEANING
WORKSTATION 1
WORKSTATION 2
WORKSTATION 3
1.26
1.40
1.53
1.66

= 1).

Fig.(8.6b1).



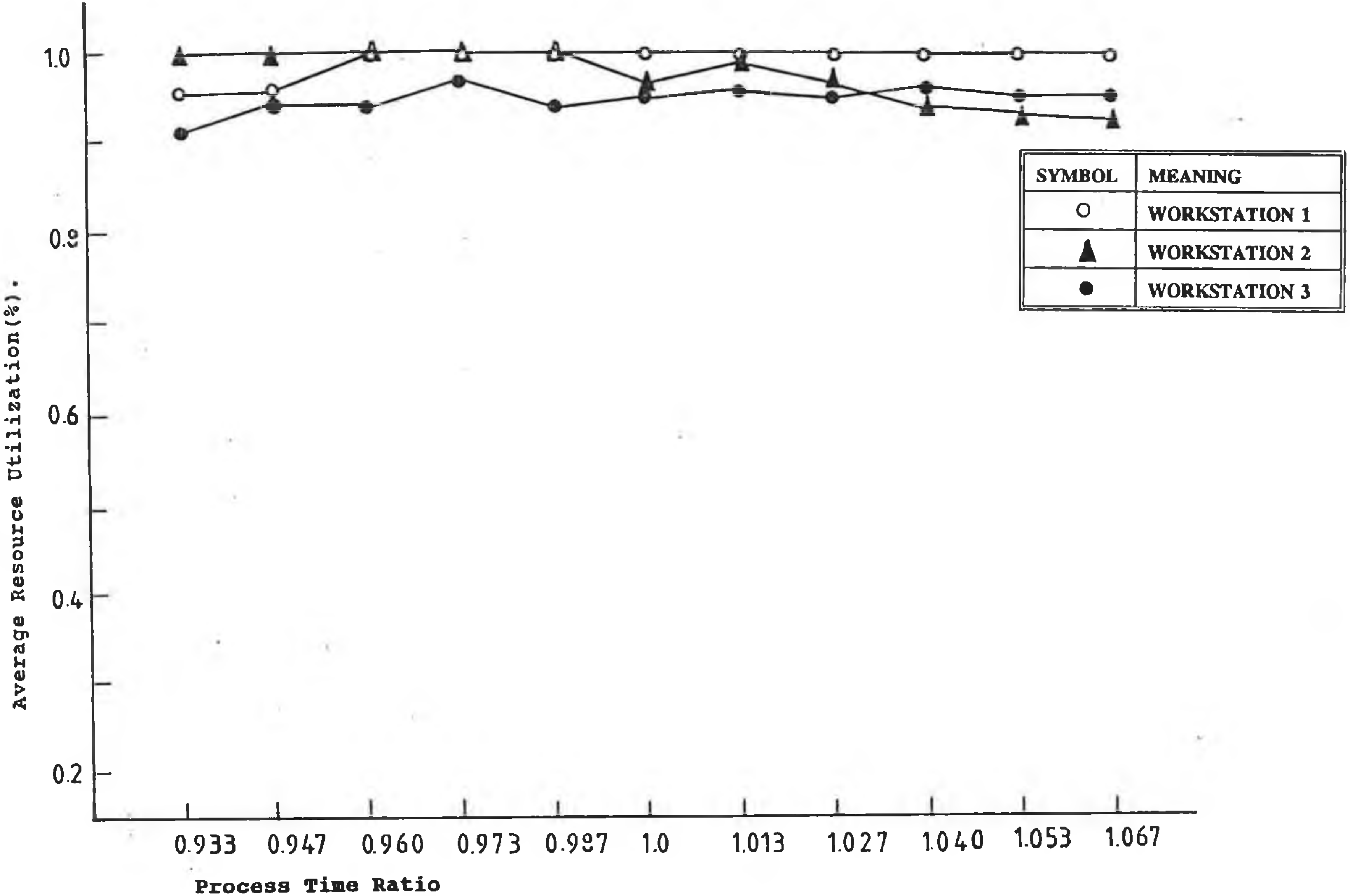
Individual Average Resource Utilization(See-Saw,σ =



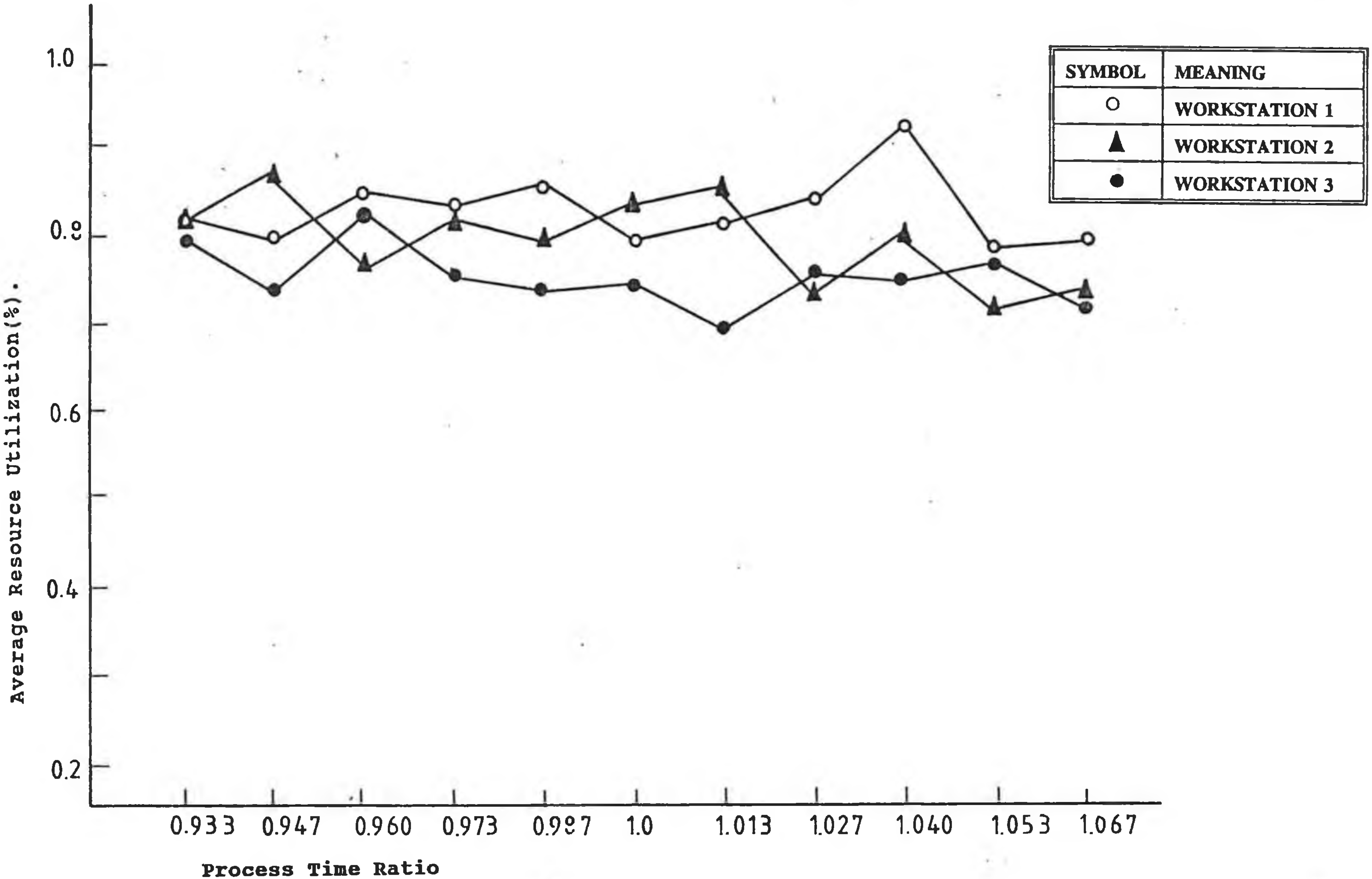
SYMBOL
MEANING
WORKSTATION 1
WORKSTATION 2
WORKSTATION 3
1.26
1.40
1.53
1.66

= 5).

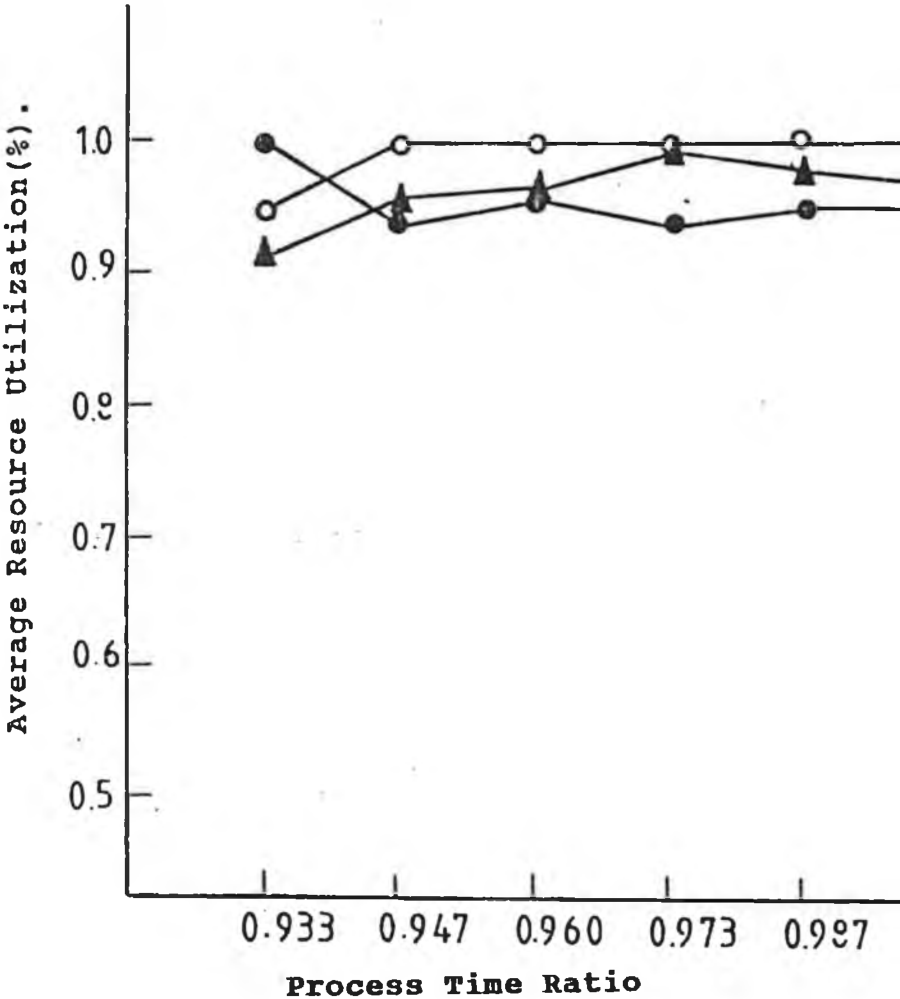
Fig.(8.6b2).

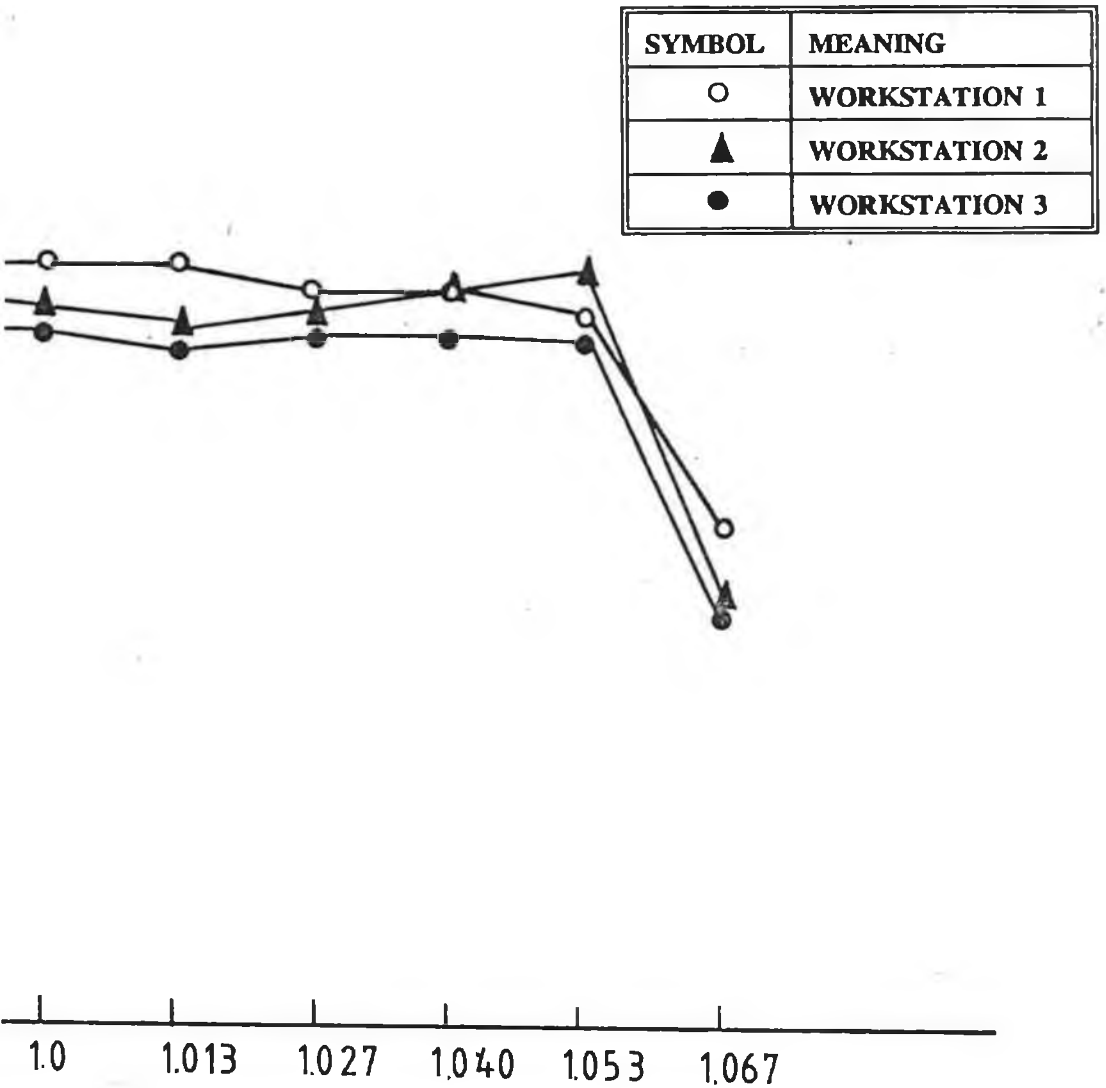


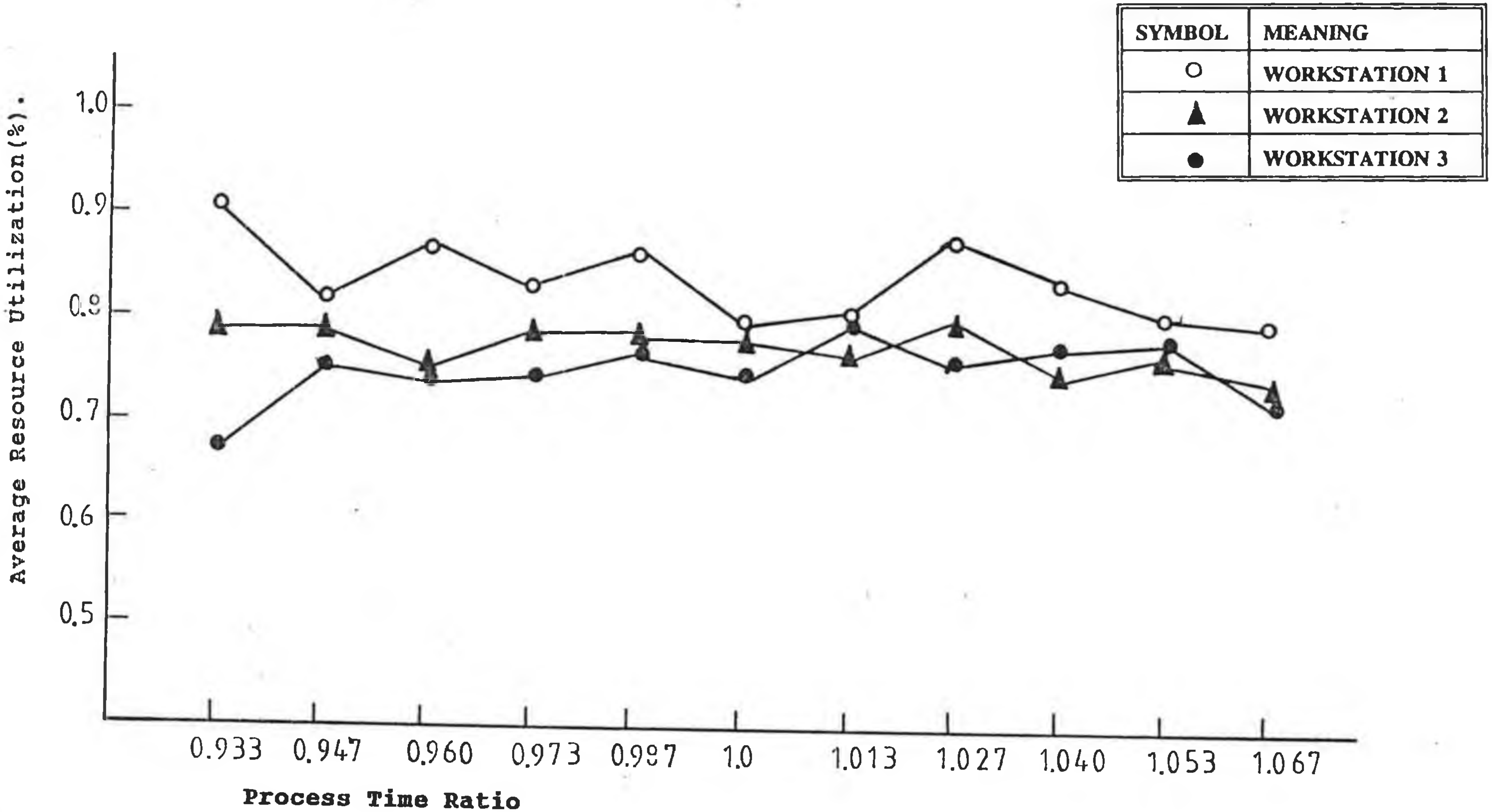
Individual Average Resource Utilization(3-Stage Bowl,σ = 1). Fig.(8.6c1).



Individual Average Resource Utilization(3-Stage Bowl,σ = 5). **Fig.(8.6c2).**


Average Resource Utilization(%).
1.0
0.9
0.8
0.7
0.6
0.5
0.933
0.947
0.960
0.973
0.987
Process Time Ratio


SYMBOL
MEANING
WORKSTATION 1
WORKSTATION 2
WORKSTATION 3
1.0
1.013
1.027
1.040
1.053
1.067



Individual Average Resource Utilization(4-Stage Bowl,σ = 5).

Fig.(8.6d2).

however, that once balance has been achieved, and the processing time at the third station, reduces, the rate at which utilization drops of is much greater, than with the cantilever case, due to the cumulative effect of the previous stations increase in processing time and its own reduction. The graph also demonstrates the extent to which the second station, - which has a constant processing time - is dependant upon the first. As the processing time ratio increases, the utilization of the second resource increases although at a slightly slower rate than that of the first. Once balance is achieved however, and the processing time at work station one rises above that of work station two, the utilization value begins to drop off, fairly symmetrically about the balanced state. A similar symmetry is seen in the queue length graph. (Figs. 8.6b1, 8.6b2).

An increase in the variance value, produces almost the same effect as that seen in the cantilever case.

<u>**3 Stage Bowl**</u>

Although the 3 stage bowl produces a large range in queue length, during its concave state, the actual utilization of each of the resources is fairly constant. The sudden drop off in utilization values see in both the see saw and cantilever case is absent. Utilization values, would appear to be dictated to by their position in the line, and not by actual work in progress. Work station one has the greatest utilization value, followed by two and three respectively, the change from a concave to convex system would not appear to affect this.

The introduction of higher variance values tends to both reduce the utilization figures of each and every resource and introduce a greater variability at each resource. A wider range of utilization values are also produced, although individual utilization values would still appear to be dictated to by their positions in the line (Figs. 8.6c1, 8.6c2).

<u>**4 Stage Bowl**</u>

The 4 stage bowl graphs are rather similar to that of the three stage bowl in that they are farily linear, utilization values tend to follow position in the line, and also for the most part are concentrated in the same small range. However when stations 2and 3, are at there greatest processing time values, a sudden drop off in utilization values of all three stations is seen. The introduction of the higher variance value, again tends to increase the range of utilization values and decrease the linearity of the graph, but also destroys the rapid decrease in utilization, seen at high values of processing time ratio, at the lower variance value. (Figs. 8.6d1, 8.6d2).

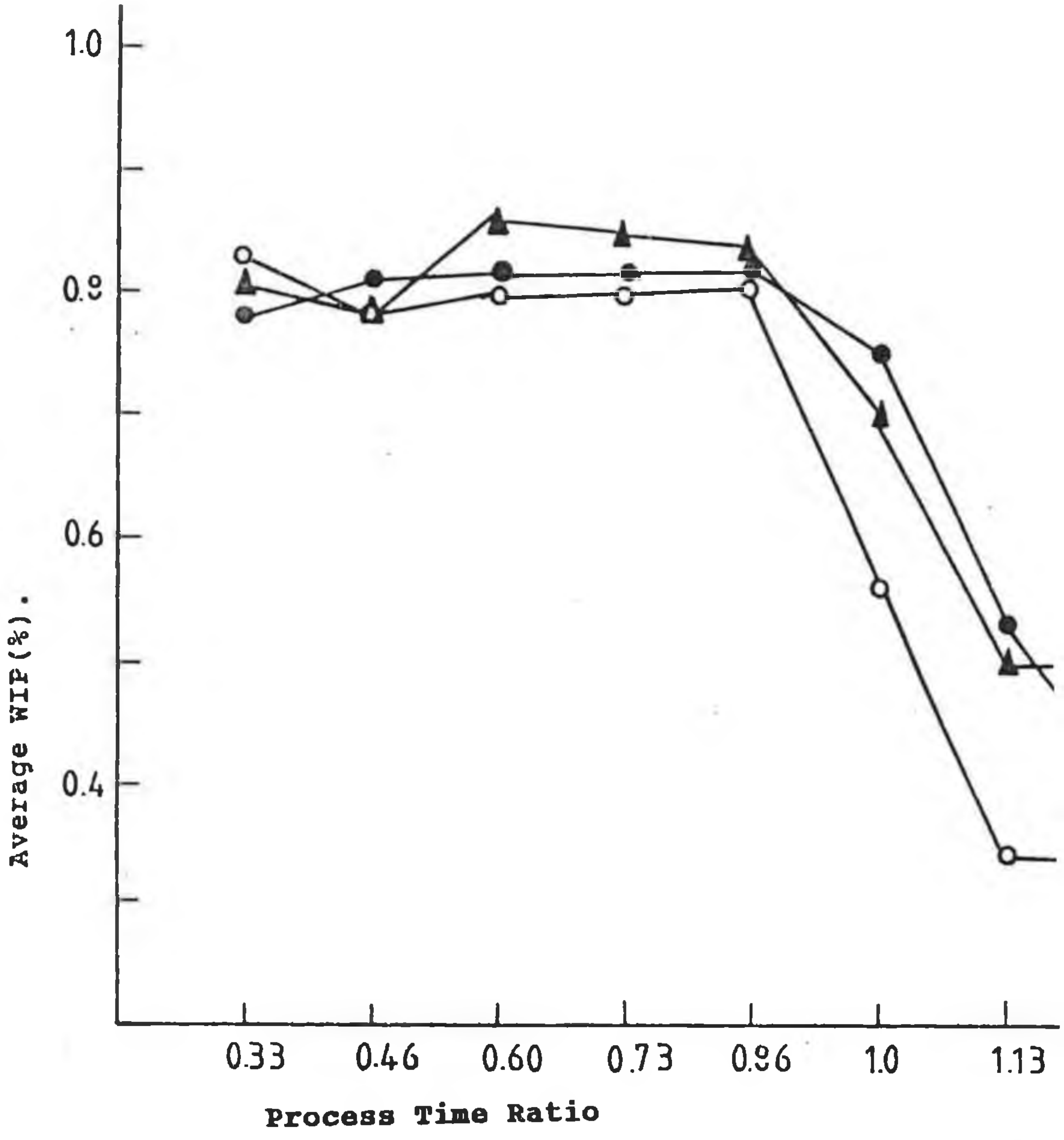
__Effects of Processing Time Variability on Overall Work in Progress and Resource Utilization__

The general trends of both overall utilization, and overall WIP values in the see saw and cantilever case would appear to be similar. Utilization graphs are convex, the higher the variance value the flatter the curve, and overall WIP curves, are a distorted 2 shape, with the smaller variance value, producing the greatest WIP range, and the lowest WIP levels. In contrast, the bowl graphs are fairly linear in shape, again however the smaller variance value produces the greatest utilization, and the smallest work in progress. In utilization and overall WIP terms therefore it is possible to say that an increase in the variance of either a cantilever or see saw configurations tends to bring the system more in tune with a bowl like configuration. Production rate and cycle time however are not similarly effected.

Cantilever

The shape of the overall resource utilization and work in progress for the cantilever case, are farily similar to that of the see saw configuration. The utilization curves are fairly convex, taking their shape from all three stations on the line, although as the value of variance increases the curves become flatter.

As far as the WIP curves are concerned it is stations 2 and 3 which are the predominant influence, with the overall WIP curves following the general trends set



Average Overall WIP in System(Cantilever)

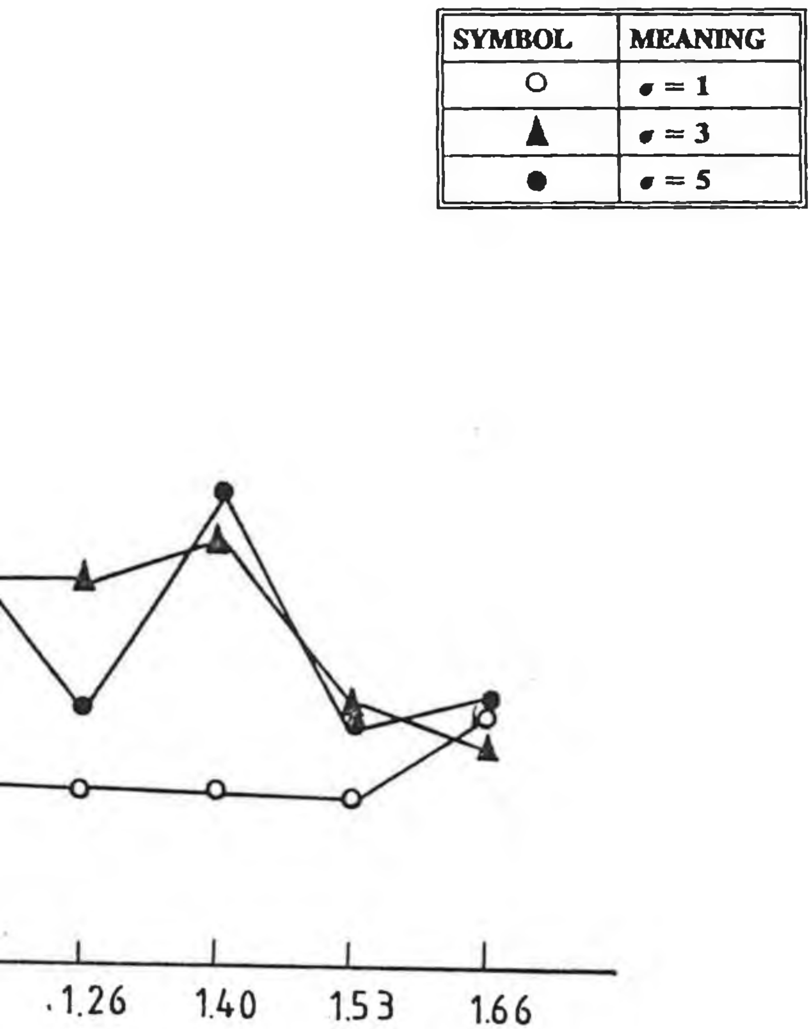
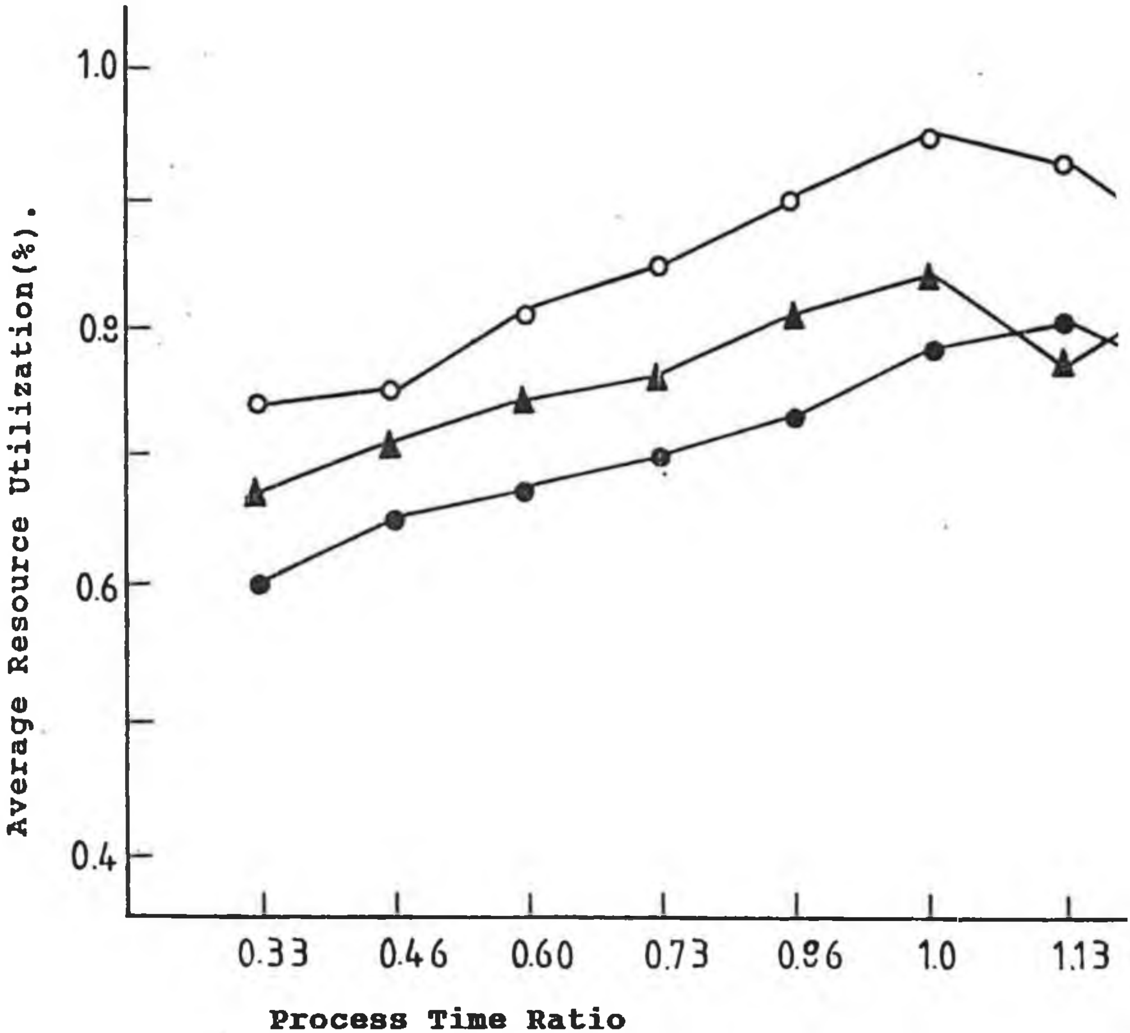


Fig.(8.7a1).



Average Overall Resource Utilization(cantilever).

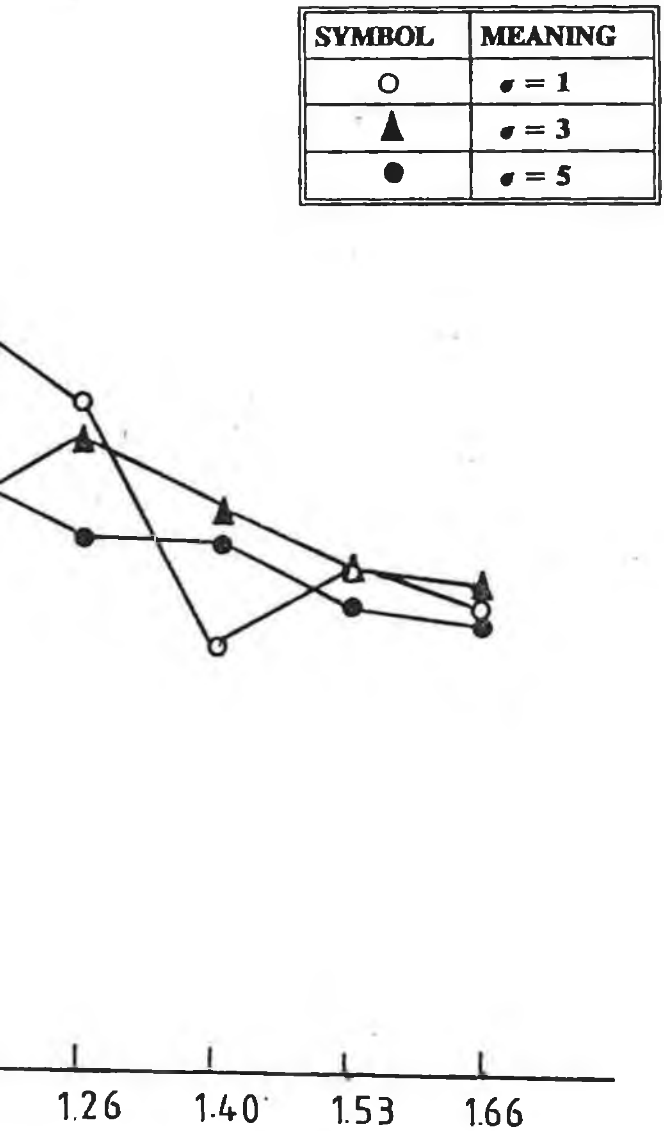
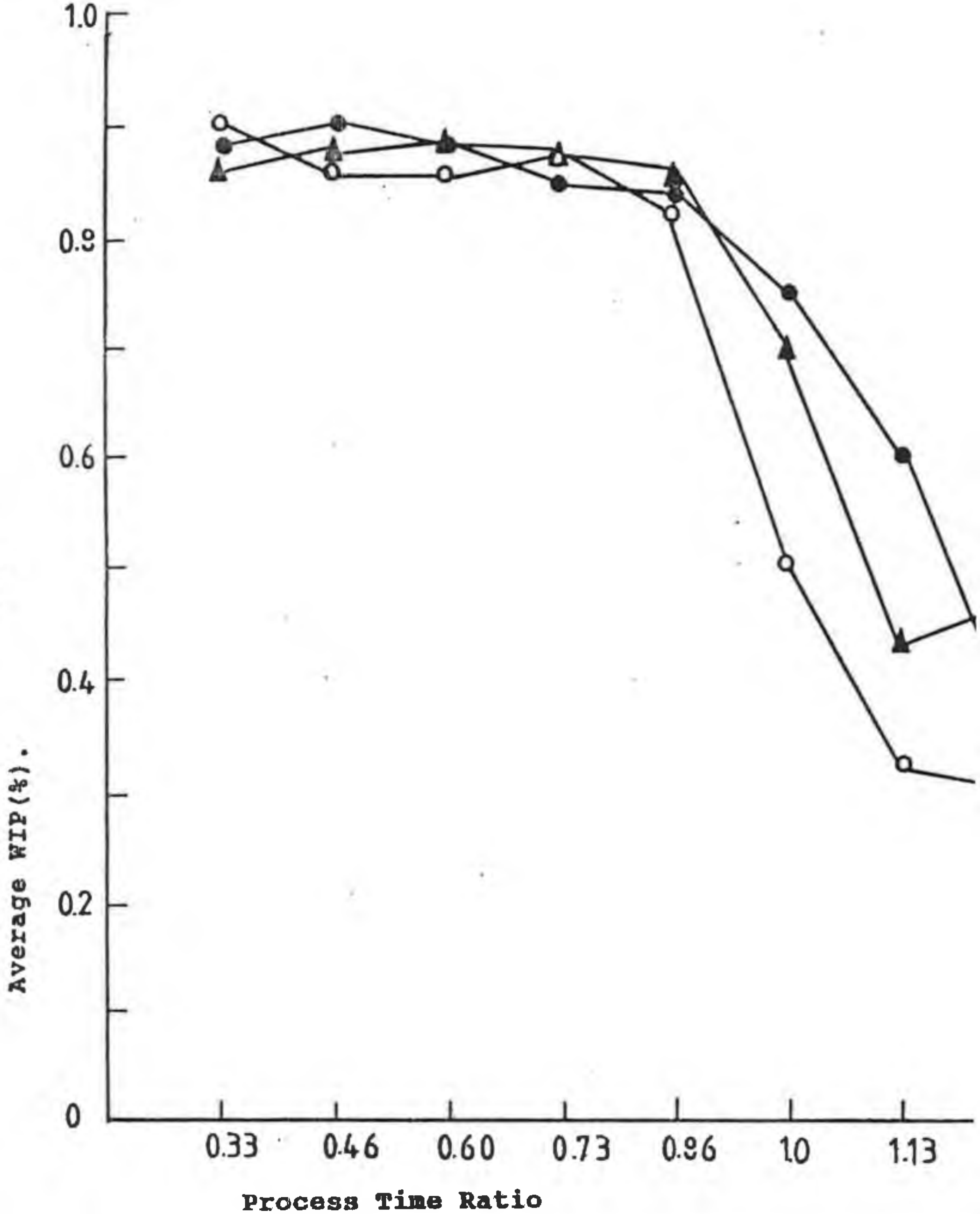
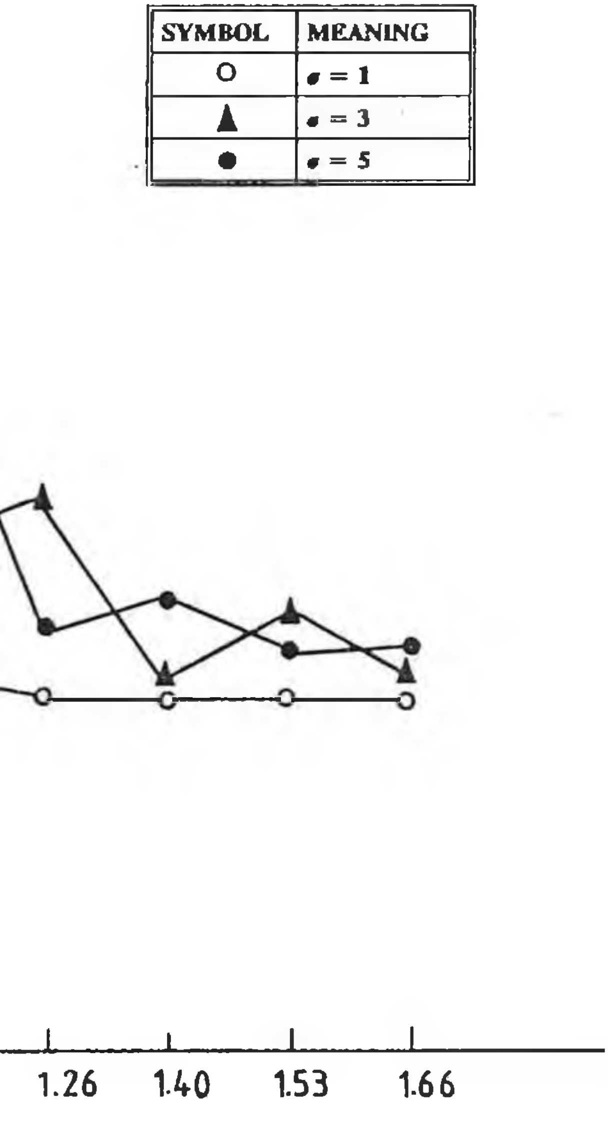
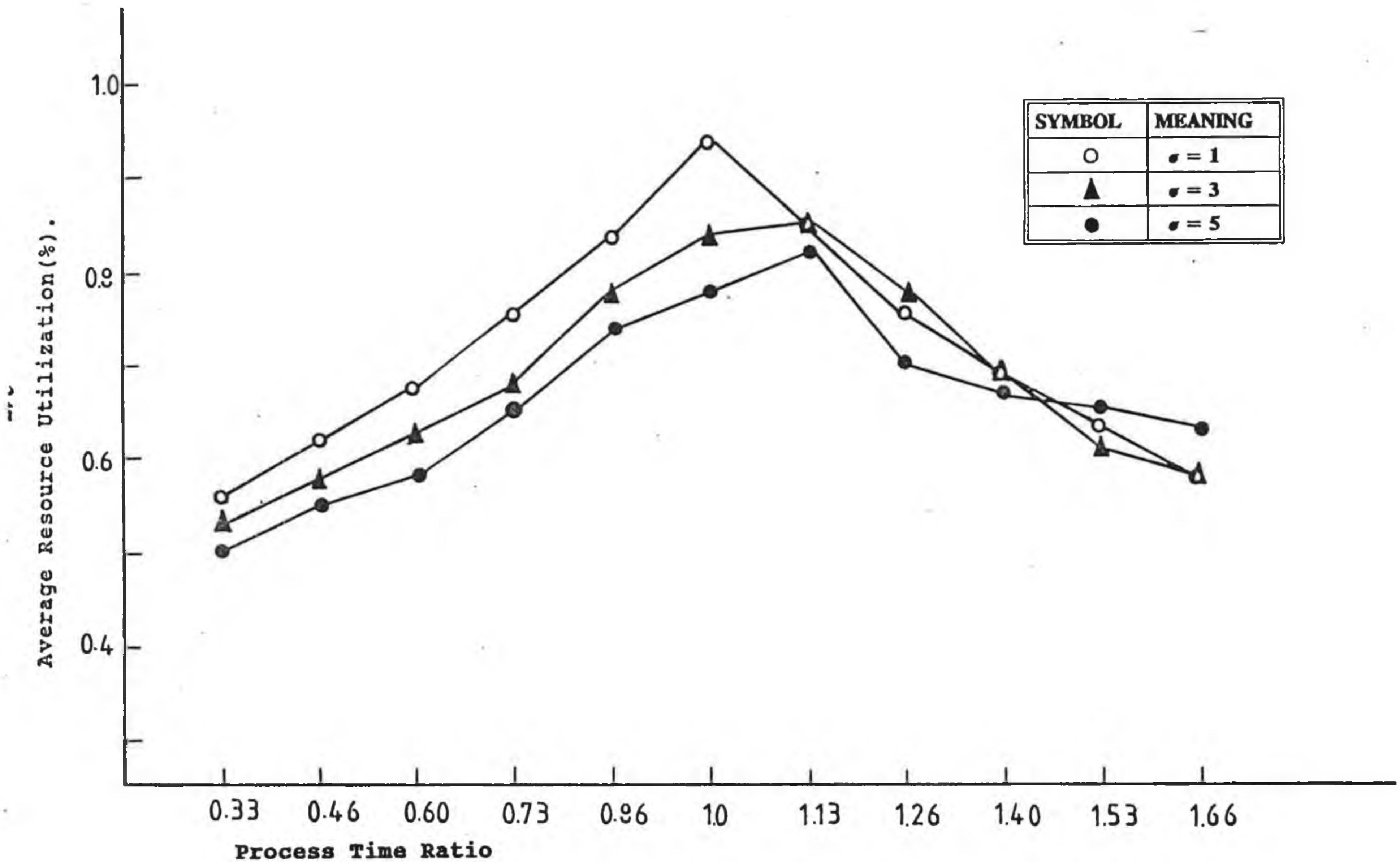


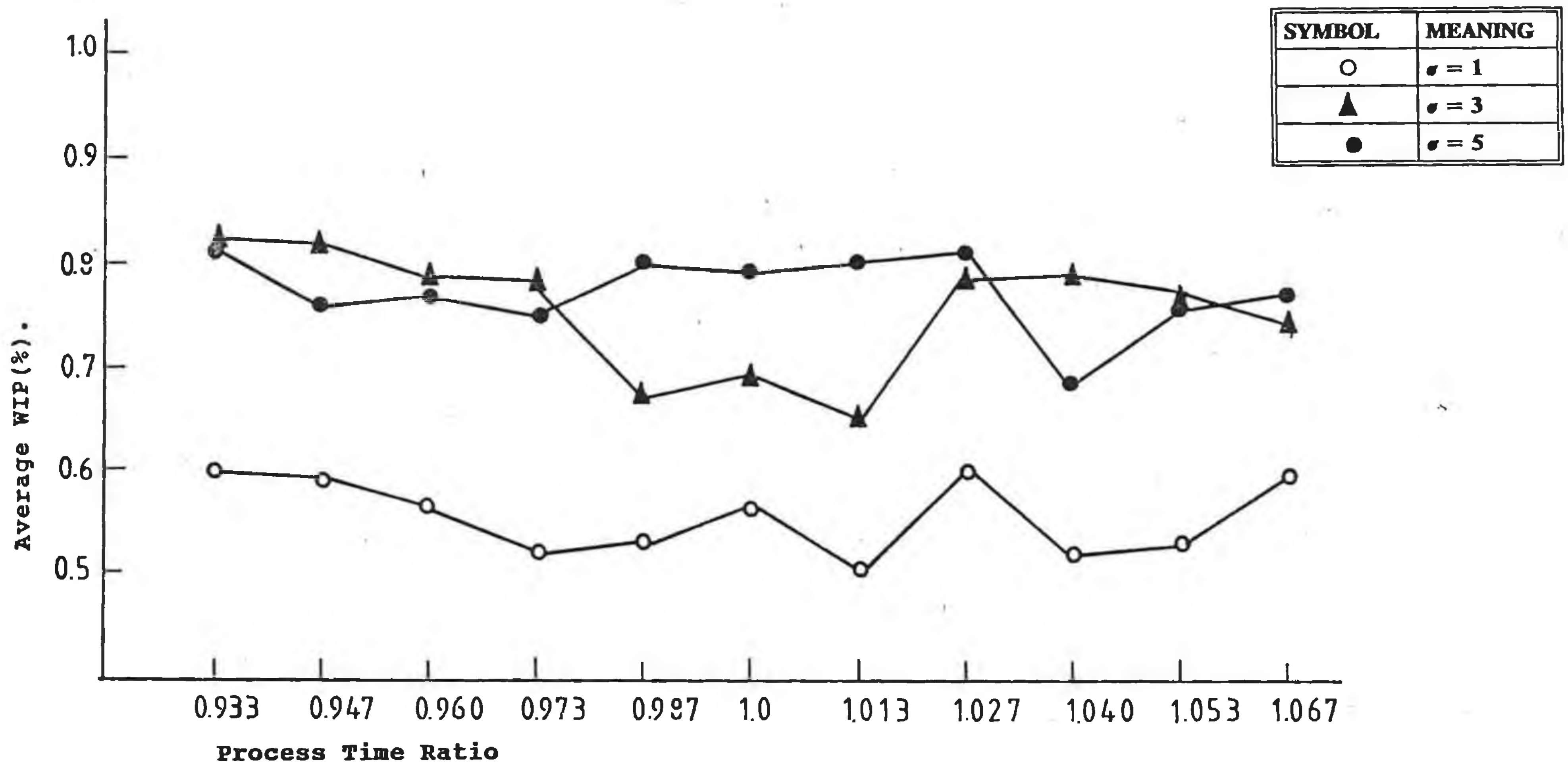
Fig.(8.7a2)


1.0
0.8
0.6
0.4
0.2
0
Average WIP(%).
0.33
0.46
0.60
0.73
0.86
1.0
1.13
Process Time Ratio

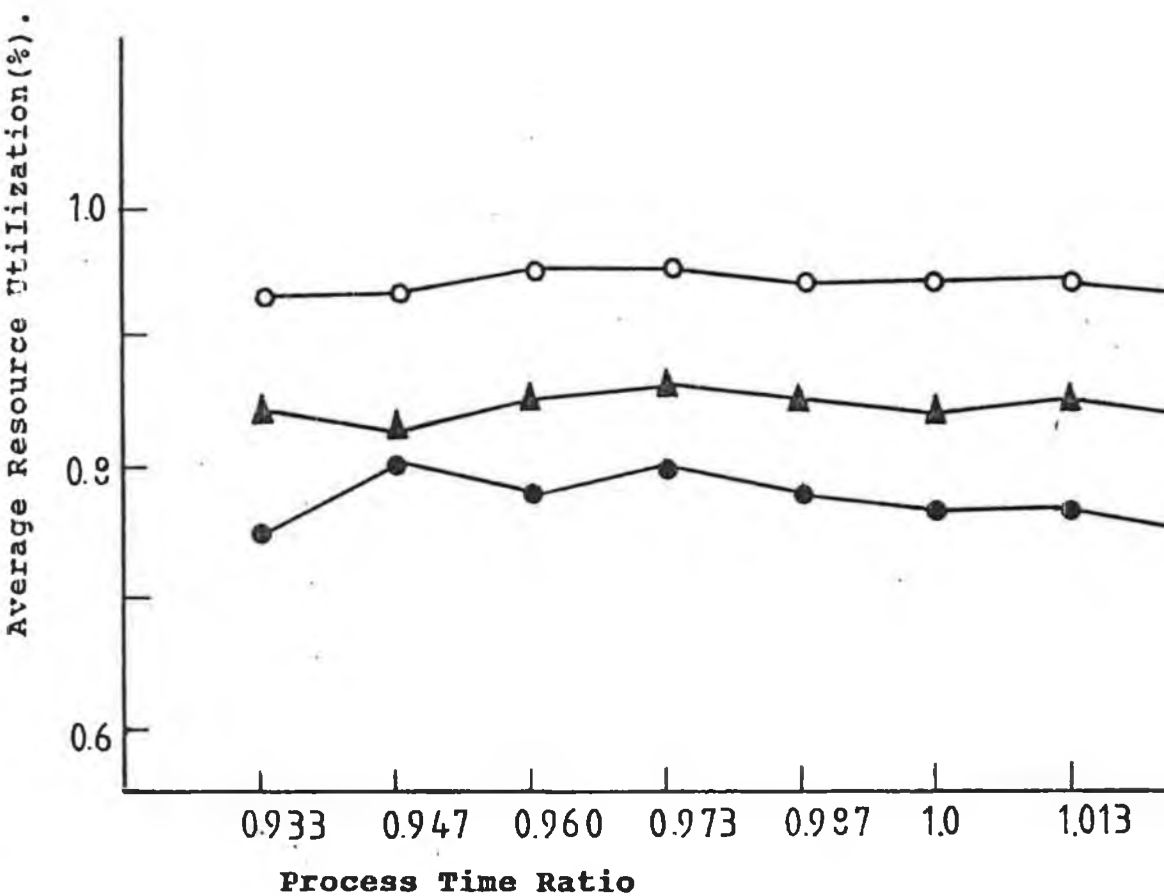

SYMBOL
MEANING
σ = 1
σ = 3
σ = 5
1.26
1.40
1.53
1.66



Average Overall Resource Utilization(See-Saw). Fig.(8.7b2).



Average Overall WIP in System(3-Stage Bowl). **Fig.(8.7c1).**



Average Overall Resource Utilization(3-Stage Bowl).

SYMBOL	MEANING
○	$\sigma = 1$
▲	$\sigma = 3$
●	$\sigma = 5$

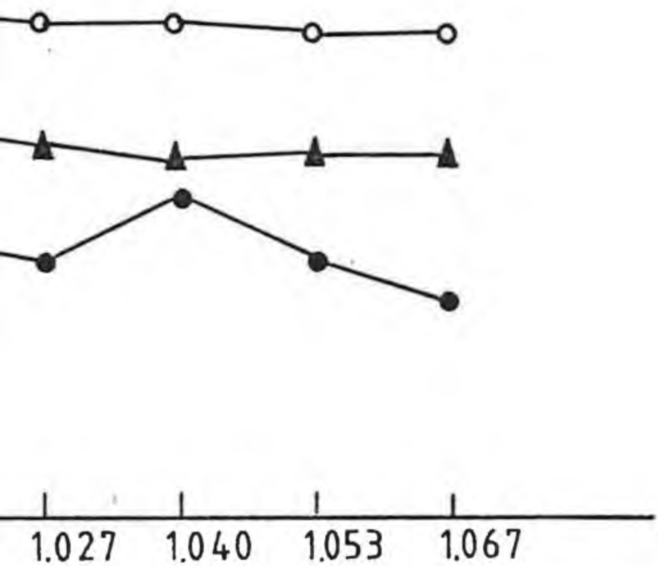
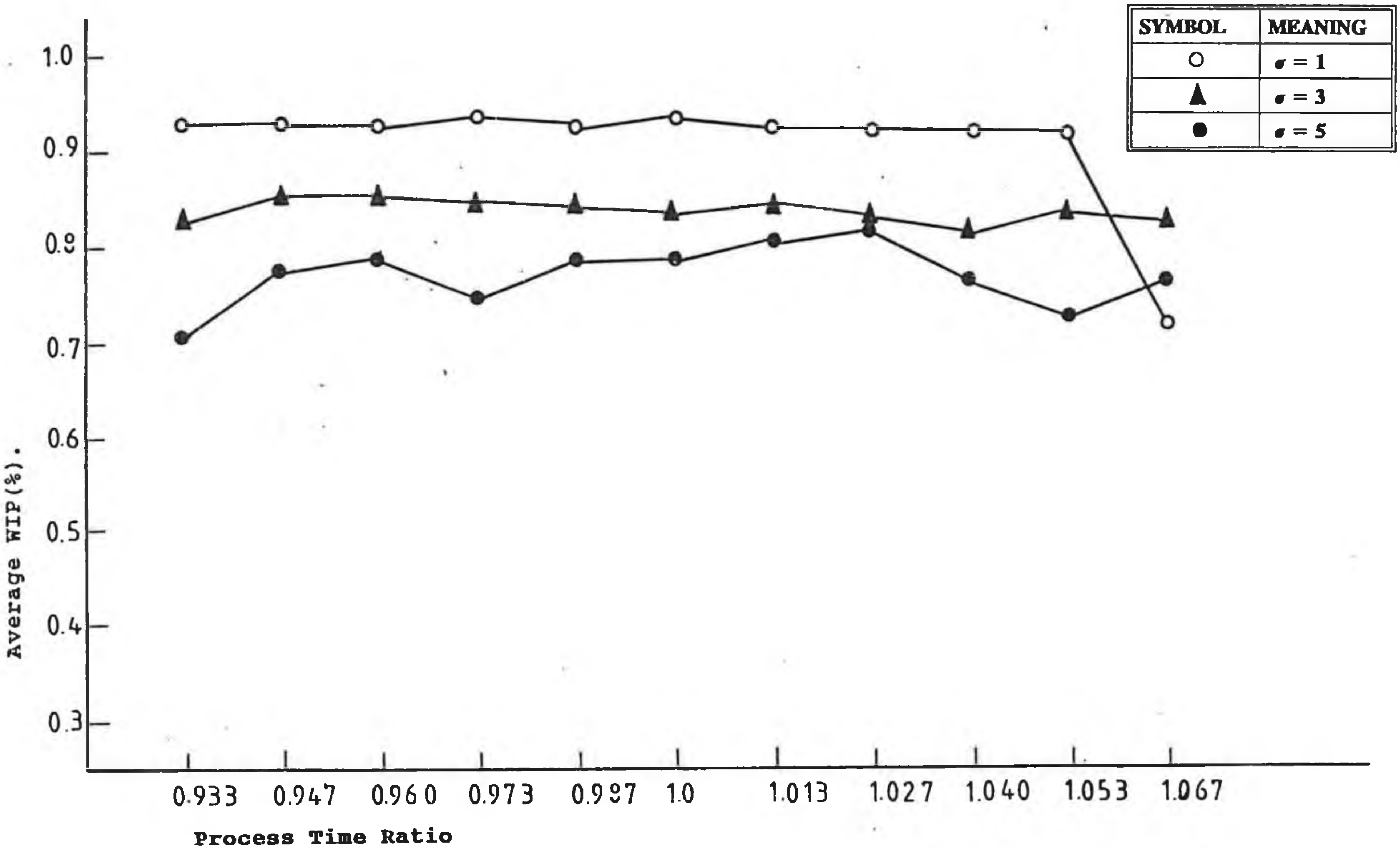
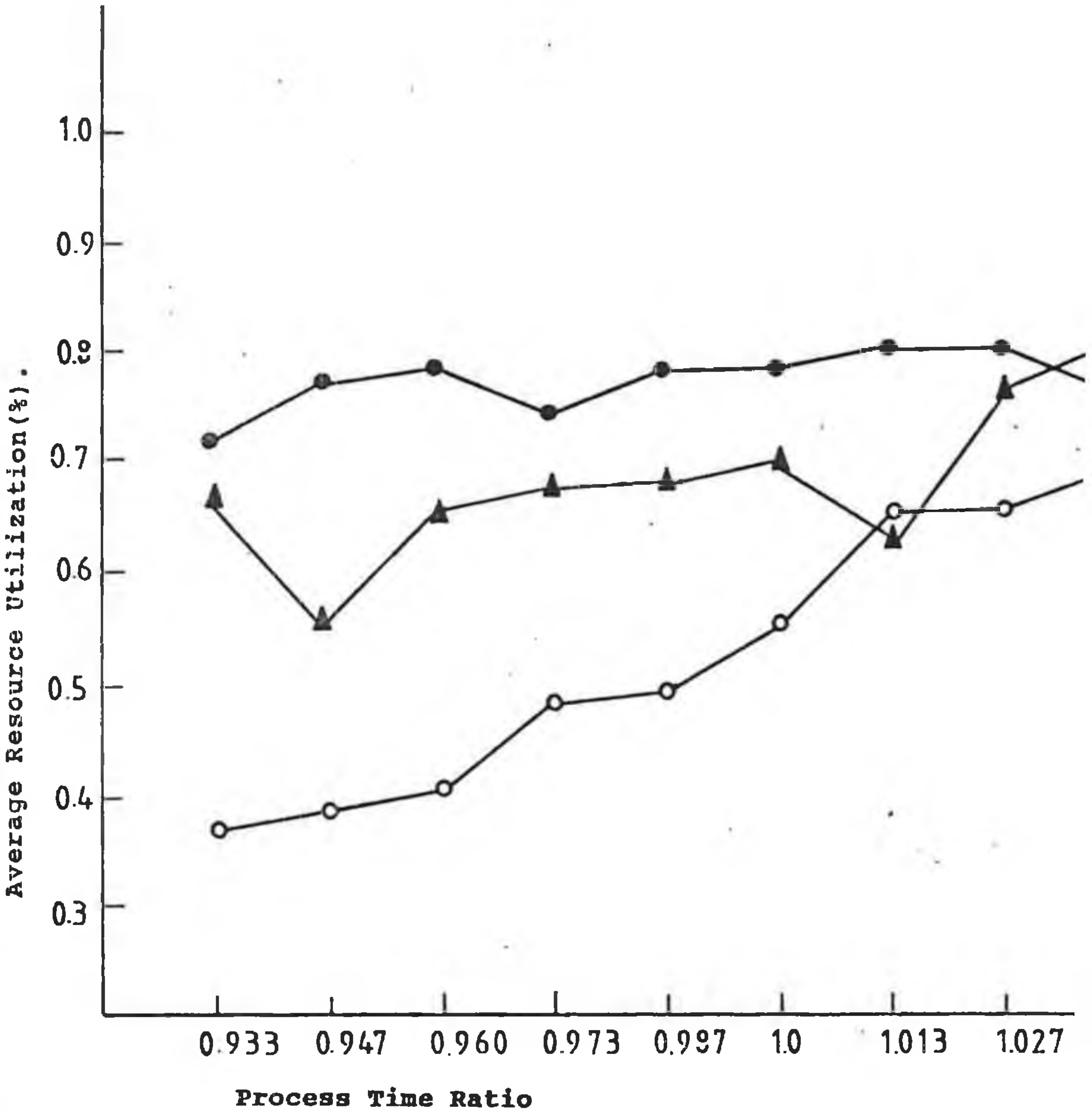


Fig.(8.7c2).



Average Overall WIP in System(4-Stage Bowl).

Fig.(8.7d1).



Average Overall Resource Utilization(4-Stage Bowl).

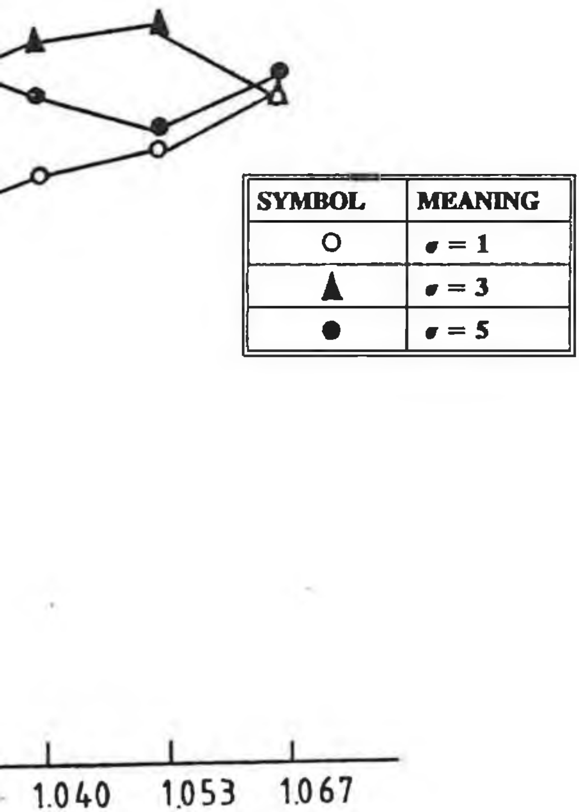


Fig.(8.7d2).

by these stations. The smaller variance values tend to produce the greatest range of WIP values. Before balance is achieved, the overall WIP level is fairly constant, although utilization figures are increasing having passed through the balanced state, utilization values begin to decrease slowly while WIP levels decrease at a faster rate, reaching a steady state quite quickly (Figs. 8.7a1, 8.7a2).

See Saw

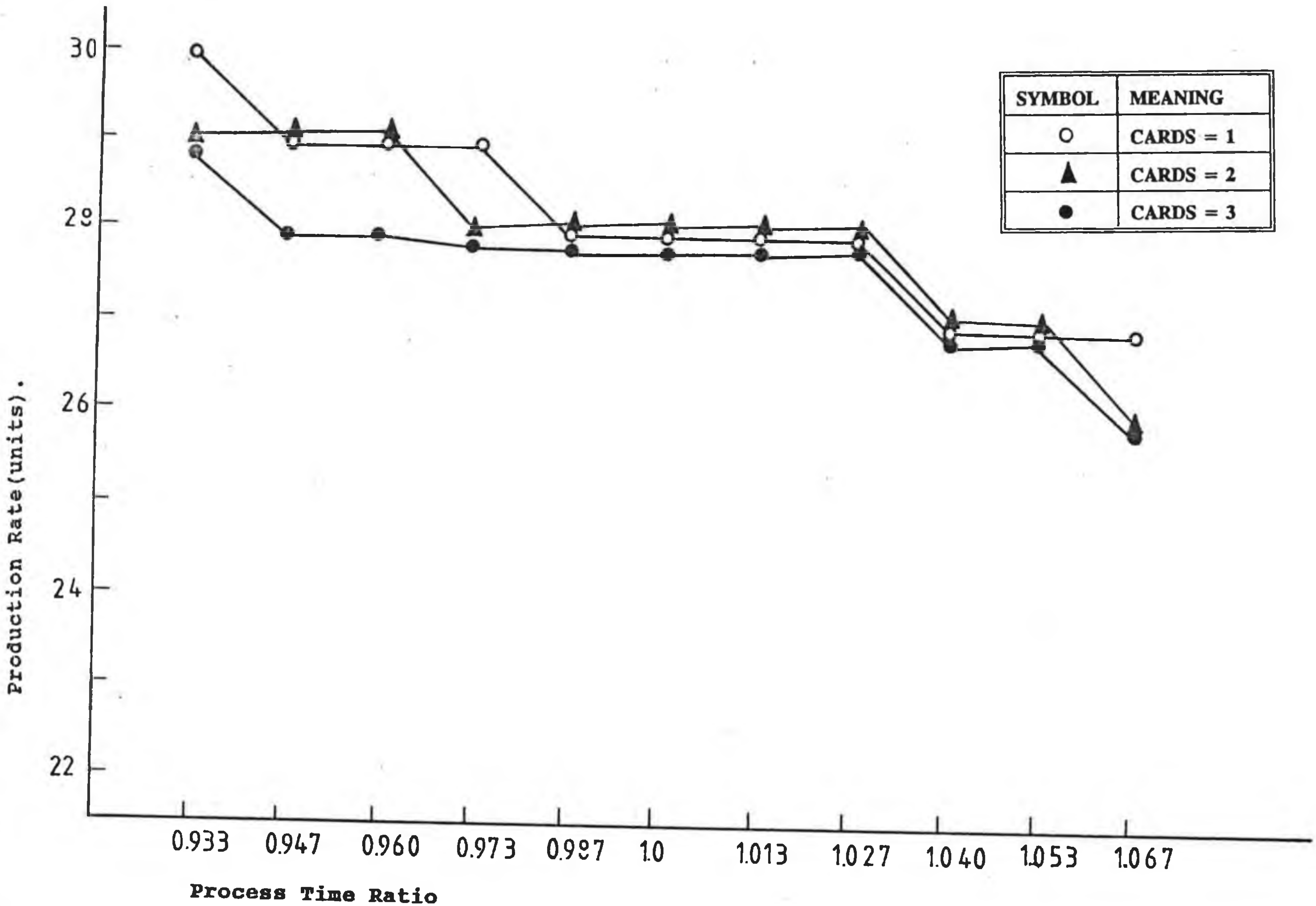
The overall percentage resource utilization, and overall work in progress levels for the see saw case are shown in Figs (5b1, 5b2) respectively. For all three variance levels it is interesting to see that in the utilization graphs, the cantilever effect on stations 1, and 3 which are opposite, but fairly equal tend to cancel each other out, allowing the overall graph to mirror the shape of work station two. The graph shows that for each level of variance, utilization values are fairly symmetric about balance, and the higher the variance value the higher the utilization value. (Fig. 8.7b1, 8.7b2). The overall WIP level in the system, can also be compared to that of an individual station, in this case work station three, because after balance, the extremes of station, 1 and 2 tend to cancel each other out.

The relationship, between the two graphs is interesting. Before balance, when the processing time at work station one is approaching that of the other two stations the level of WIP is reducing as the utilization is increasing. Once balance has been achieved, and the processing time of station one is still increasing, the overall utilization redues and so to does the WIP level.

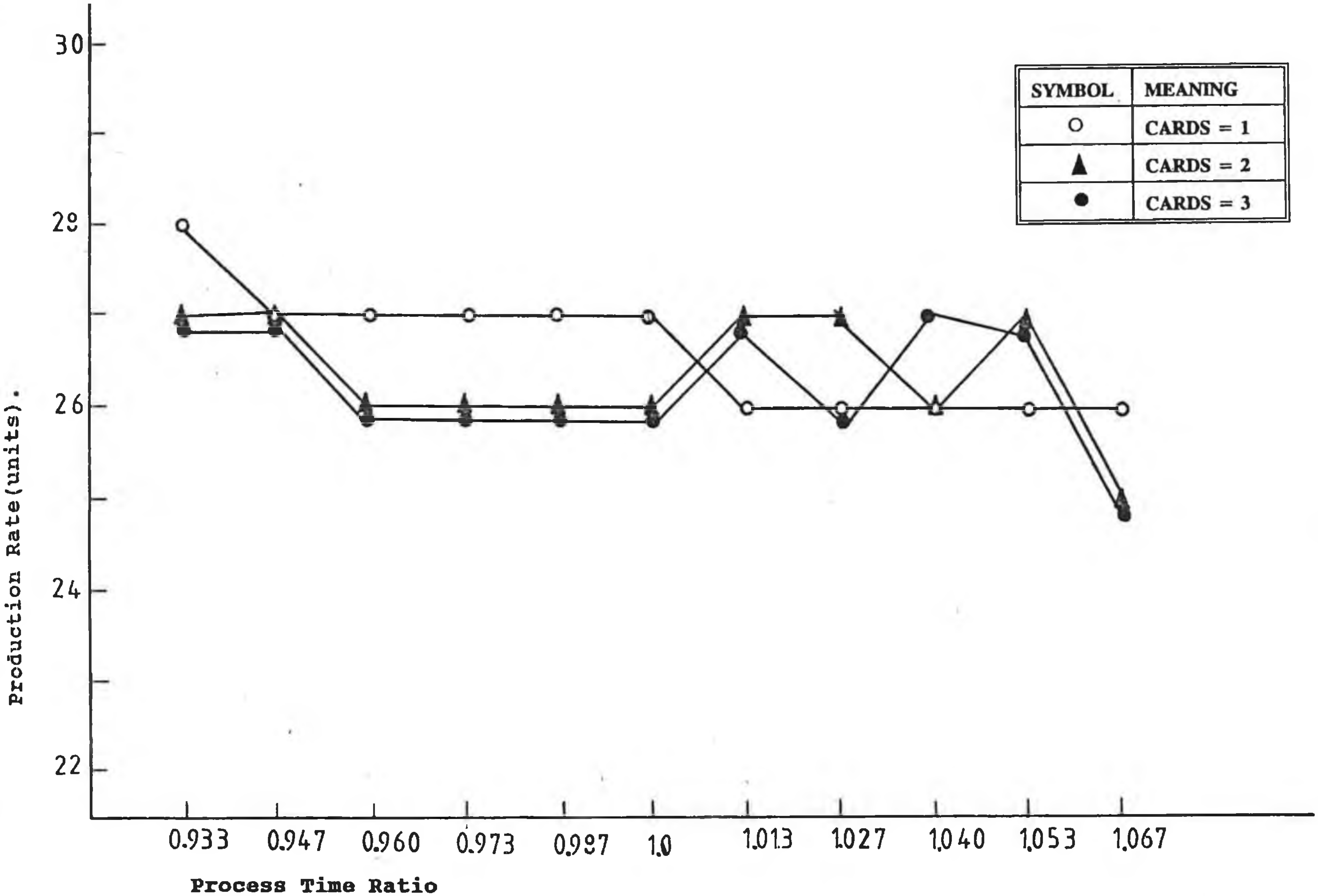
3 Stage and 4 Stage Bowl

The three and four stage bowl overall utilization graphs, show no particular deviations from the individual work station graphs. The higher the variance value, the lower the utilization and the higher the overall WIP level.

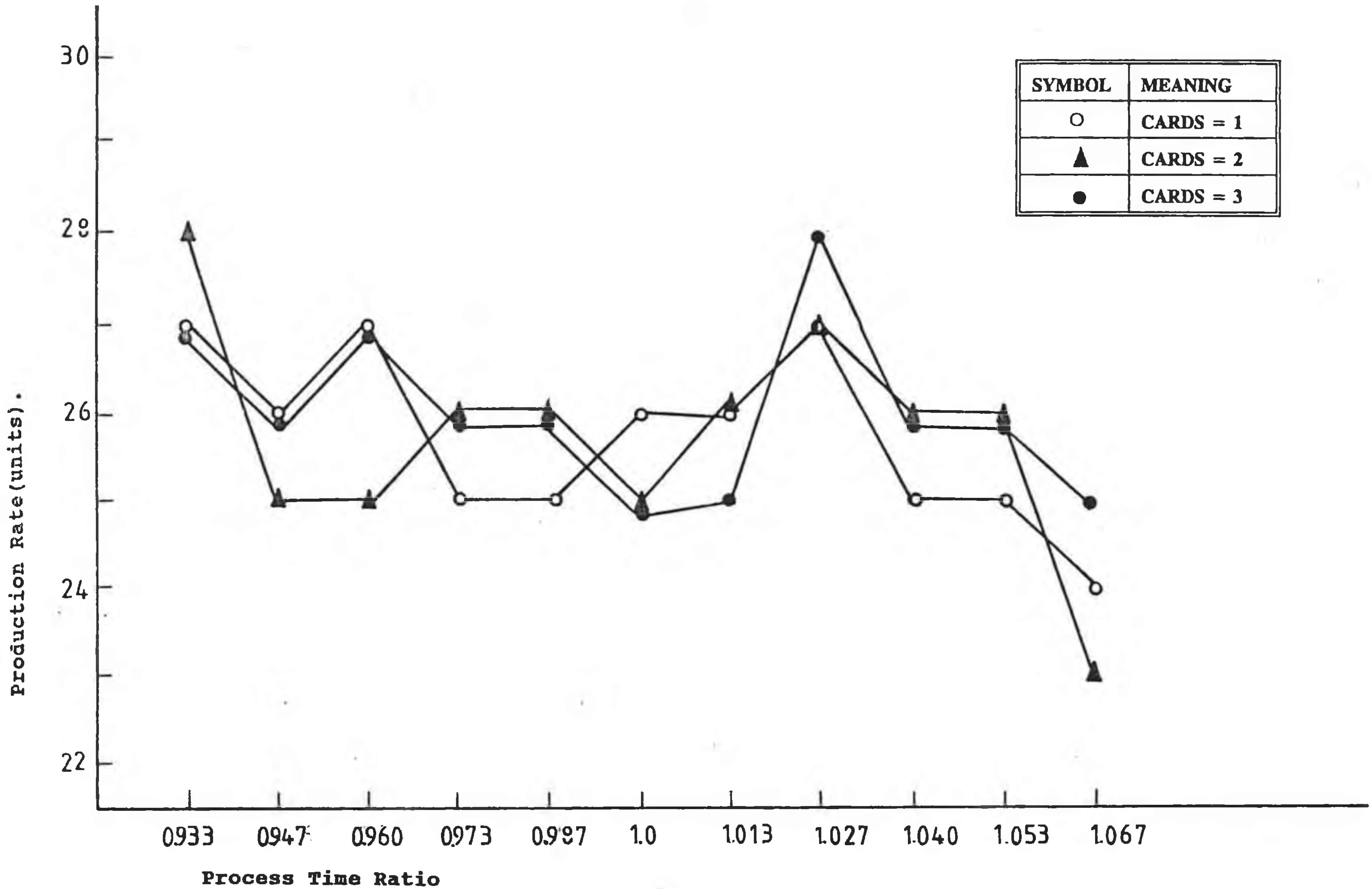
With the 3 stage bowl, the overall WIP and utilization values increase as the



Variation in Production Rate With The Number of cards(σ = 1). Fig.(8.8a1).



Variation in Production Rate With The Number of Cards(σ = 3). **Fig.(8.8a2).**



Variation in Production Rate With The Number of Cards(σ = 5). **Fig (8.8a3)**

processing time ratio increases, across the spectrum of variances. The four stage bowl graphs however show that WIP levels tend to increase with processing time ratio, although resource utilization remains constant. (Figs. 8.7d1, 8.7d2).

8.7.2 The Effect of an Increase in the Number of Kanban Cards

The previous section, shows that the two bowl type configurations tend to outperform the other two configurations under the various performance parameters chosen. The four stage bowl configuration, was therefore chosen for this set of experiments.

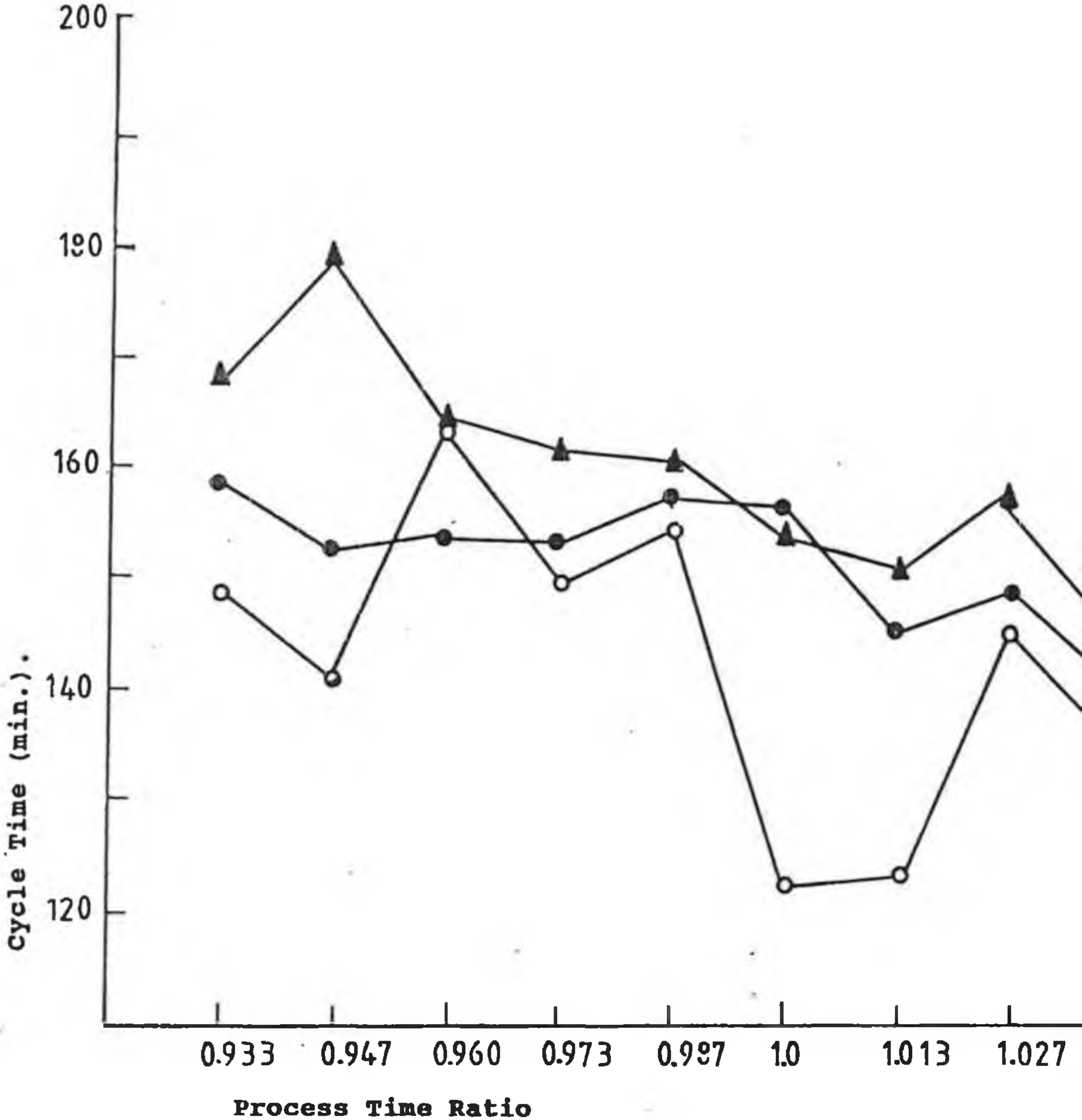
Production Rate

At low values of process time ratio, an increase in the number of cards within the system has very littel effect on the production output. At those values of PTR however where the bowl effect is most marked, the single card consistently system produces the greatest output. (Fig. 8.3). As the variance increases, the deviation in output, between the three systems increases, and the range of output increases, but is concentrated lower values.

The graphs show that as both the mean and variance values increase the correct choice of cards is important to the overall system performance, and suggests that it may be possible to compensate for an increased variance by an increase in the number of cards.

Cycle Time

An increase in the number of cards does not distort the overall cycle time graphs. Generally speaking increasing the number of cards from 1 to 2 (which causes an increase in the systems ability to 'hide' WIP) causes an increase in the cycle times across the range of PTR. However a further increase in the number of cards, does not produce a similar result, suggesting that as the WIP in the system is increased, the extent to which the relationship between the number of cards and the processing time can be relied upon to control the system is reduced. (Fig. 8.9).



Variation in Cycle Time with the Number of Cards(σ = 1).

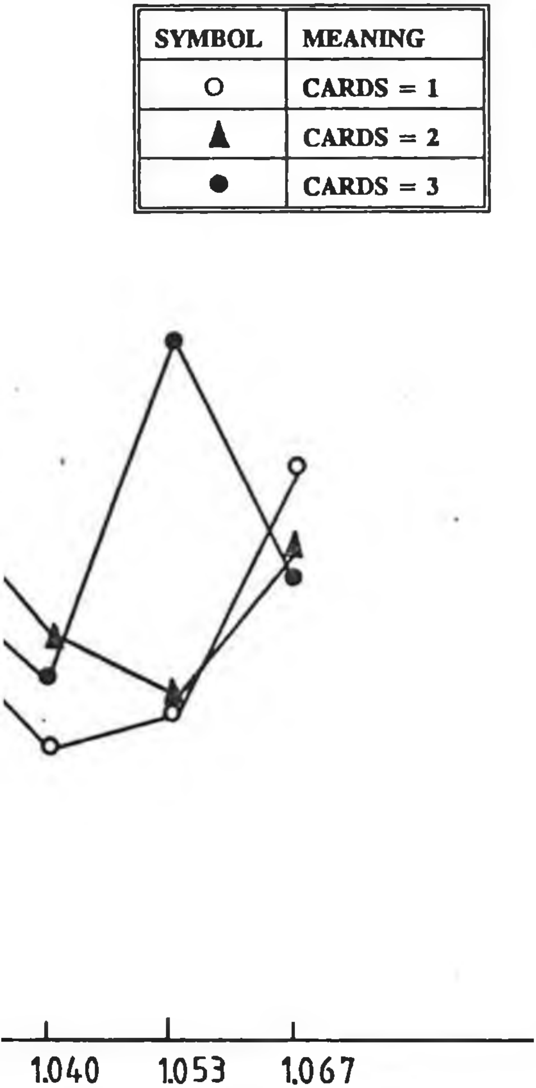
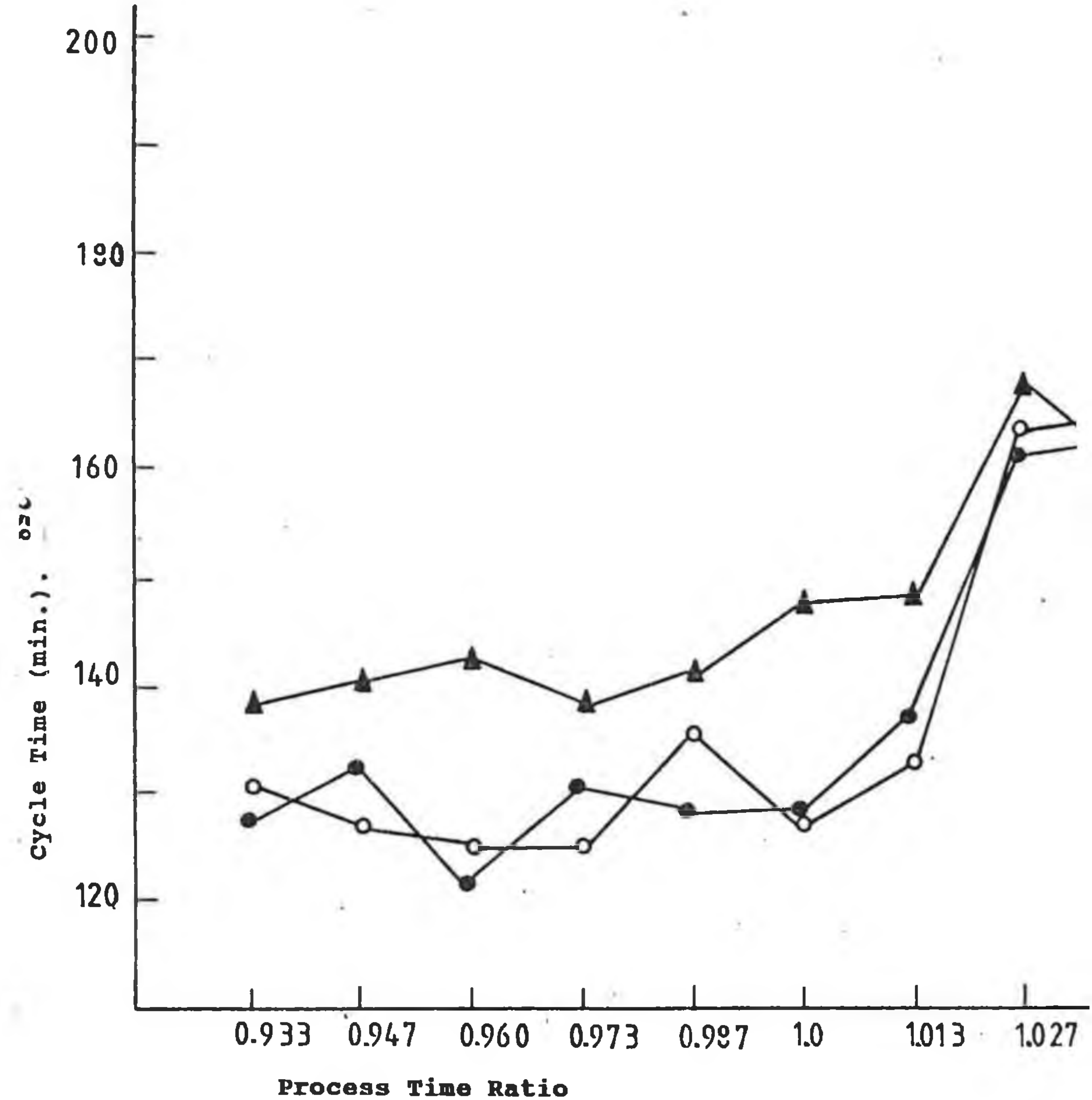


Fig.(8.9a1).



Variation in Cycle Time with the Number of Cards(σ = 3).

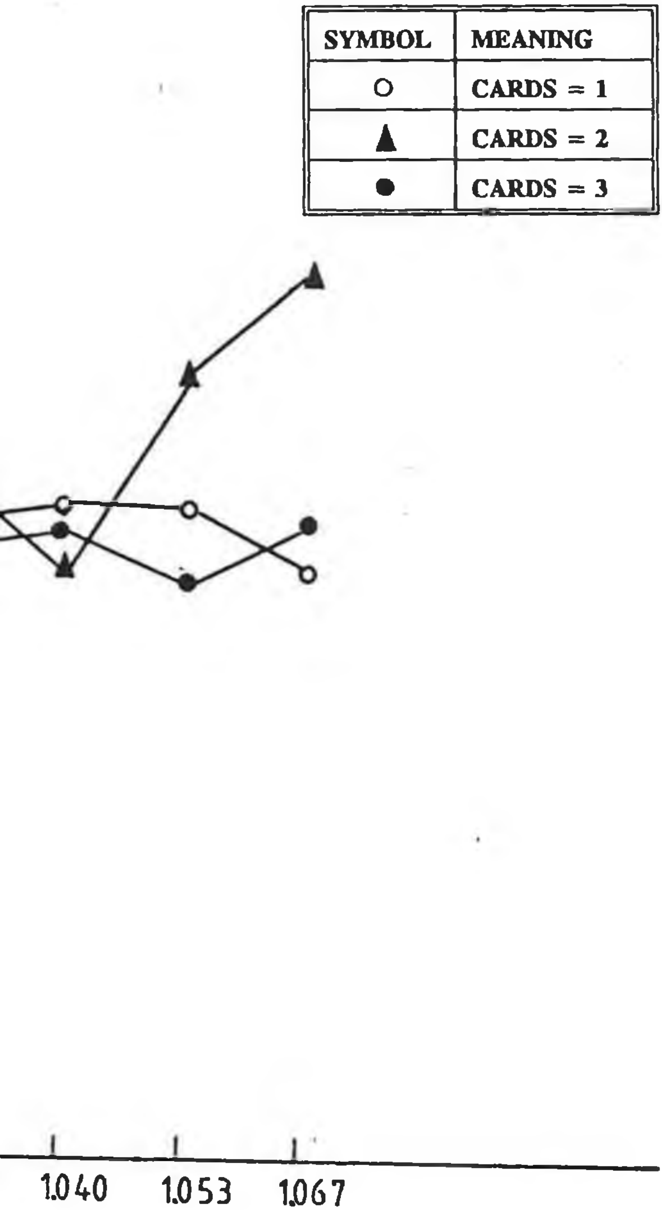
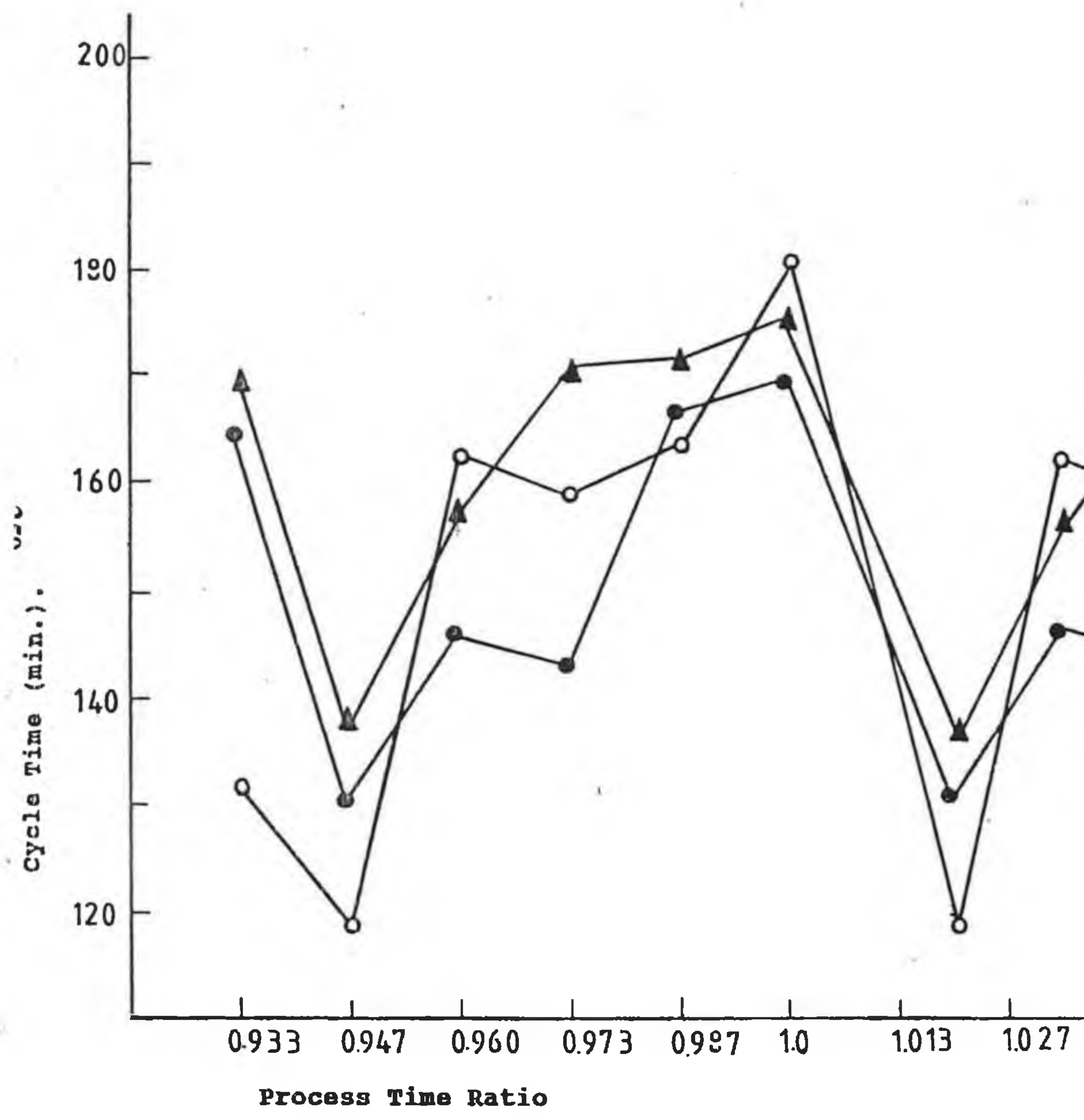


Fig.(8.9a2).



Variation in Cycle Time with the Number of Cards(σ =5).

SYMBOL	MEANING
○	CARDS = 1
▲	CARDS = 2
●	CARDS = 3

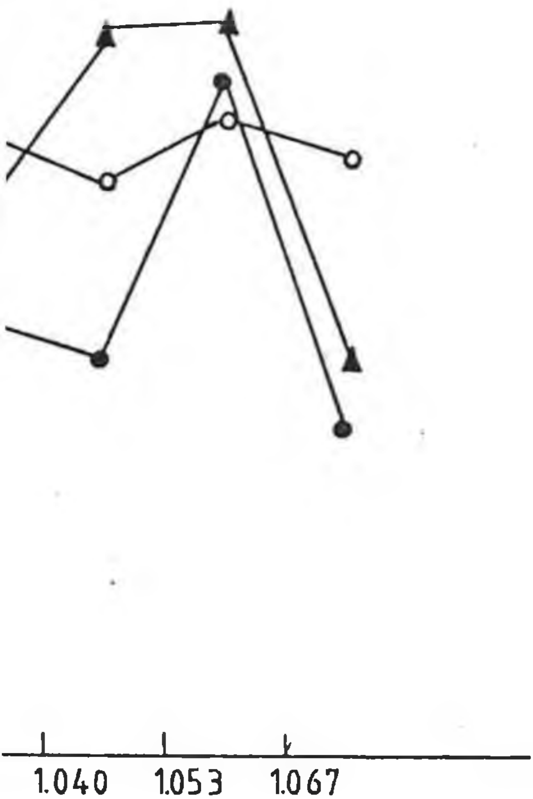
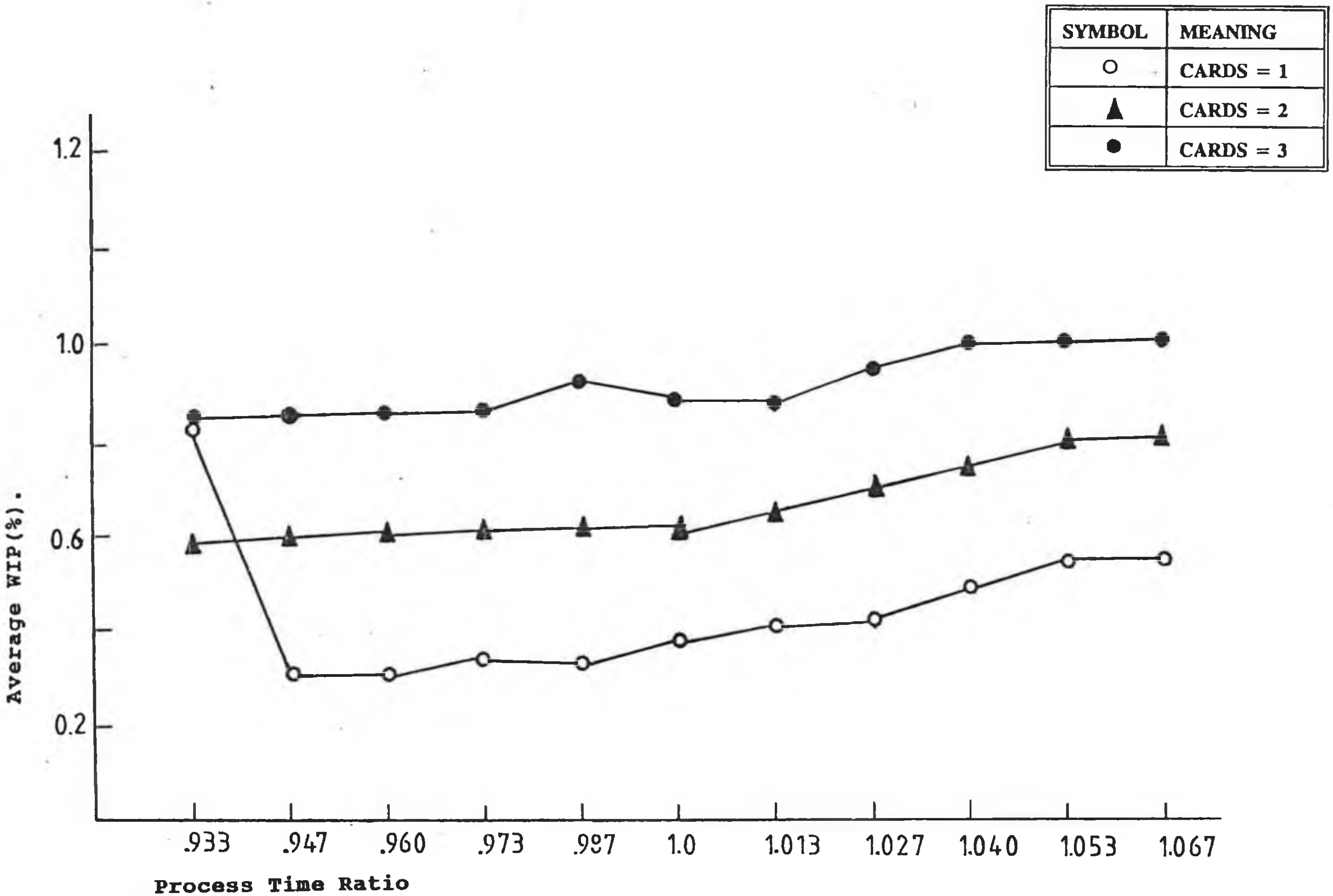
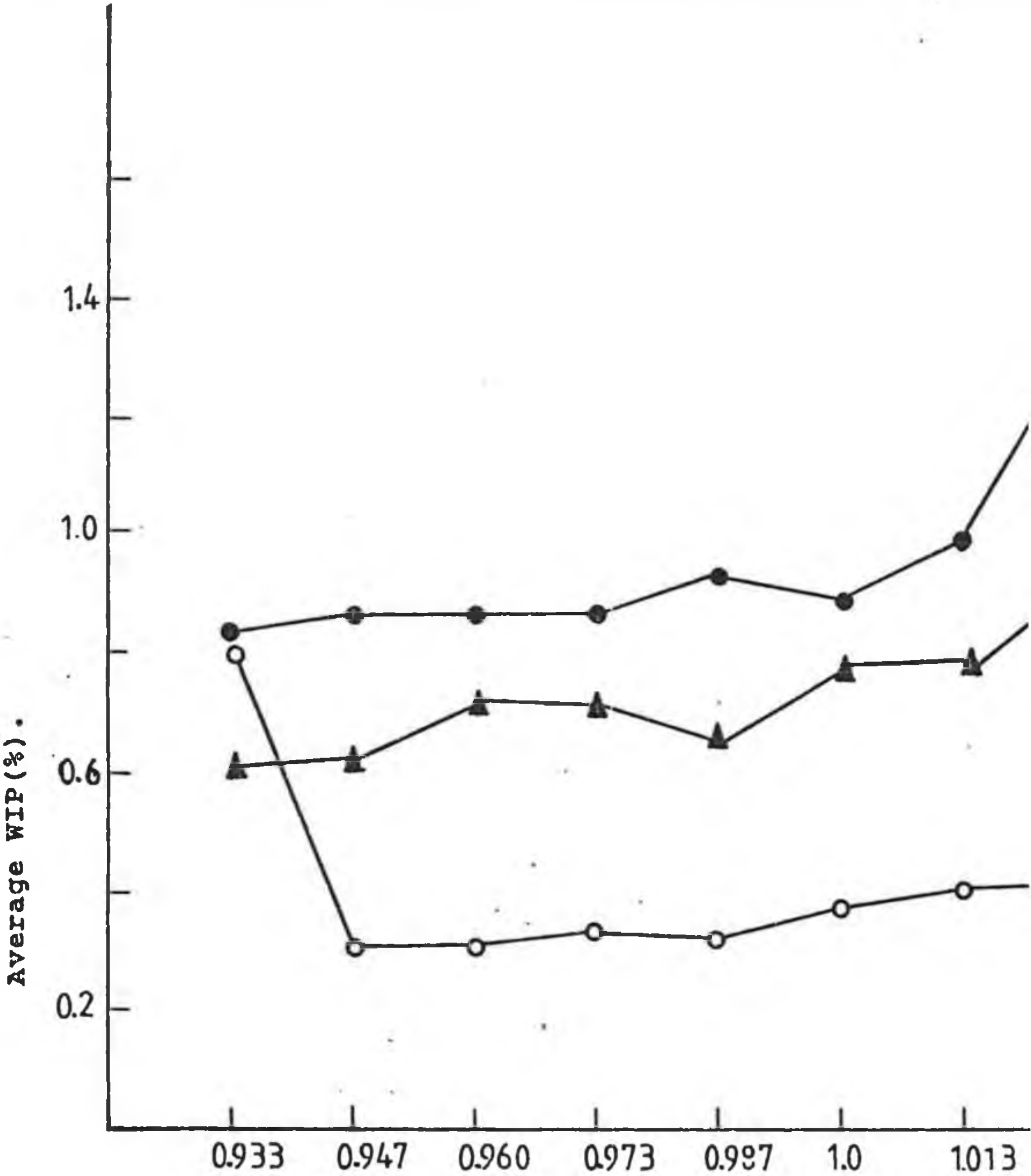


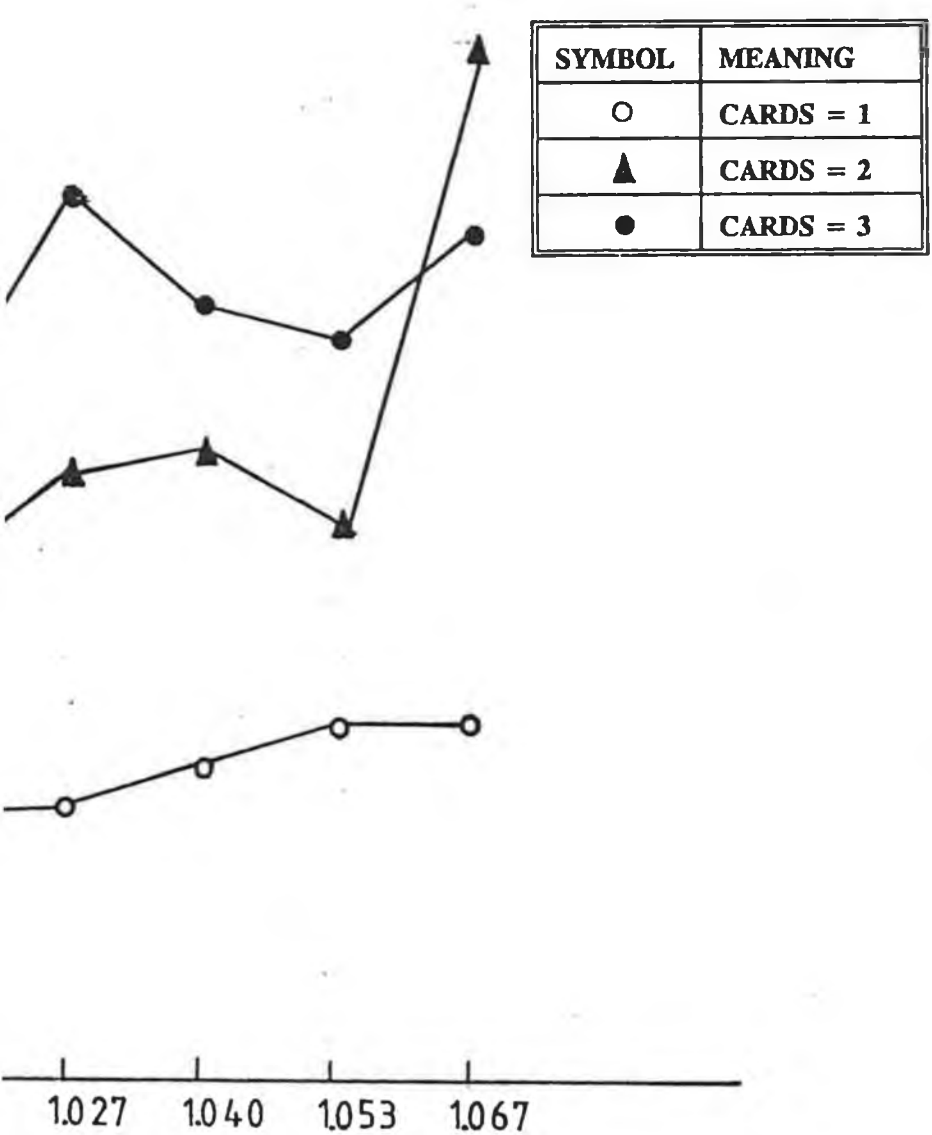
Fig.(8.9a3).



Variation in Overall WIP with the Number of Cards(σ = 1). Fig.(8.10a1).

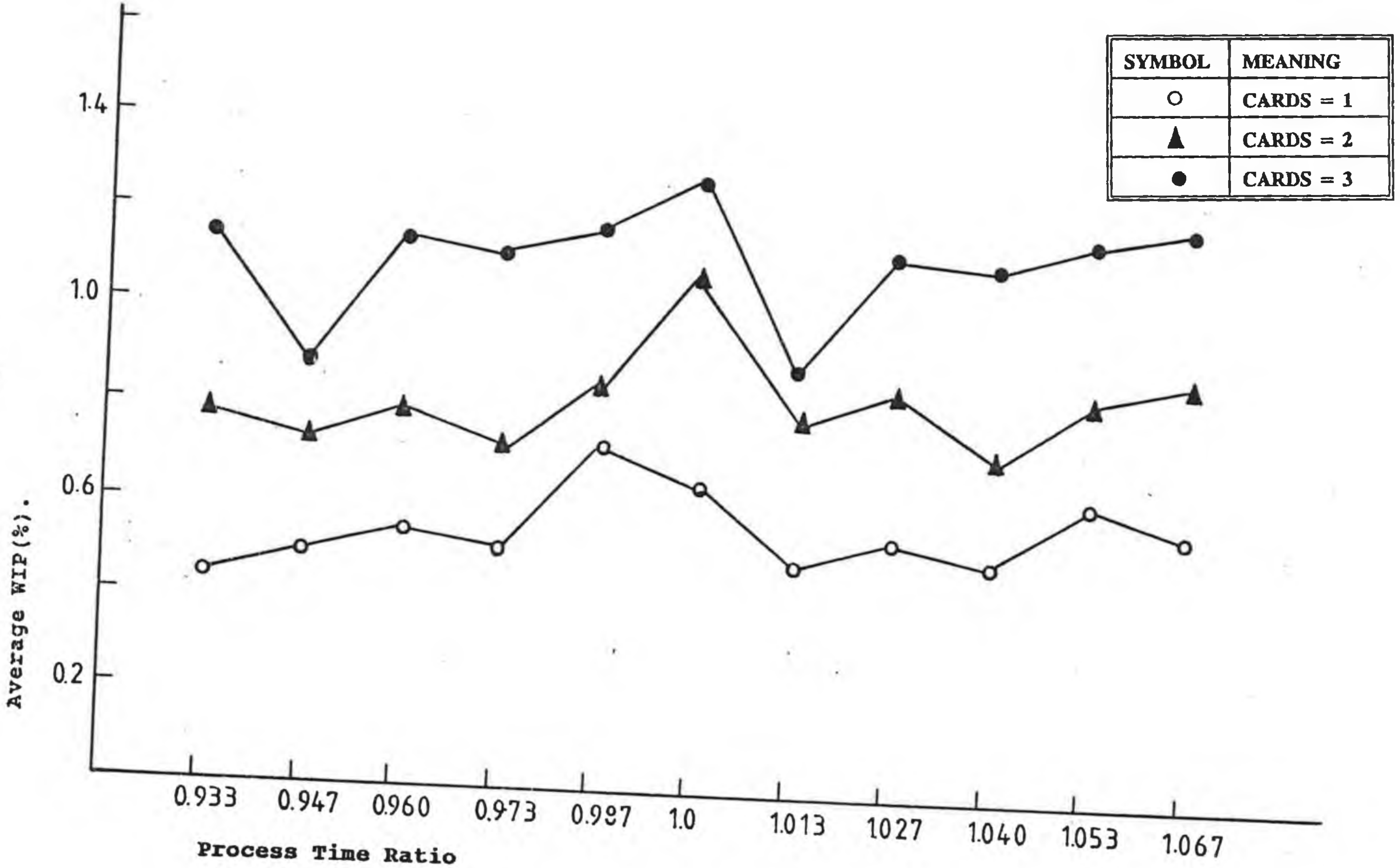


Variation in Overall WIP with the Number of Cards(σ



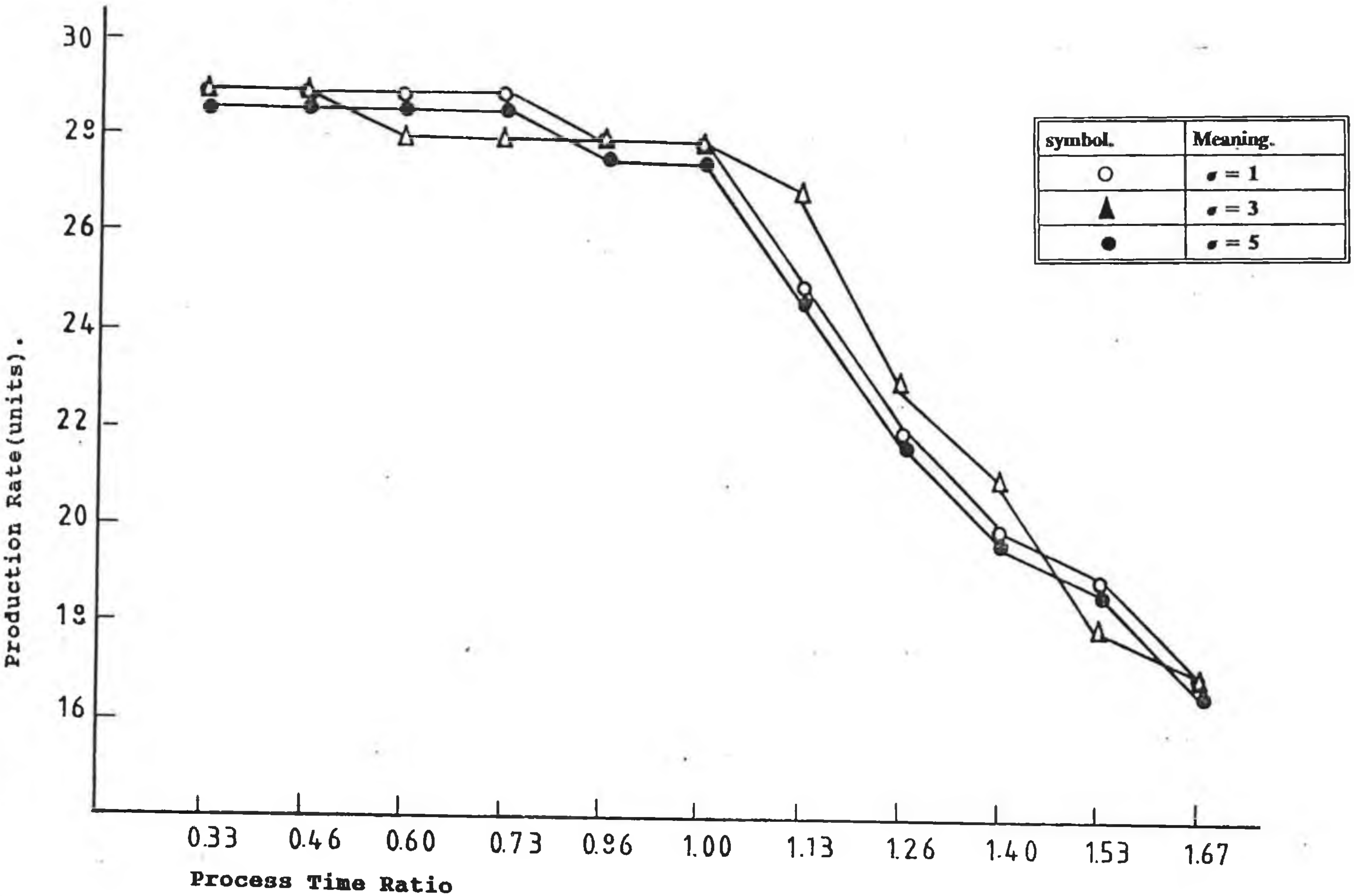
= 3).

Fig.(8.10a2).



Variation in Overall WIP with the Number of Cards(σ = 5).

Fig.(8.10a3).



Variation in Production Rate With Final Assembly Variability. Fig.(8.11).

Total WIP

As stated previously, increasing the number of cards, within a system, increases the allowable WIP within the system. Therefore a production system with 2 Kanban cards per station may have an average of two units per station. Figs. (7.9) however show that across the spectrum of PTR values, increasing the number of cards to 2 and 3, rarely causes the average level of work in progress to rise above 1. As the variance increases however, the level of work in progress does begin to increase at higher PTR values. This increase is caused by the processed units spending more time in the output buffer. At low values of variance and mean processing time, a part spends little or no time waiting to be moved to the next station. (Fig. 8.10).

Resource utilization values, show very little deviation as the number of cards are increased.

8.7.3 The Effect of an Increase in Final Assembly Variability

These experiments were carried out varying the processing time at final assembly alone, the system was operating with only one set of kanban cards per station.

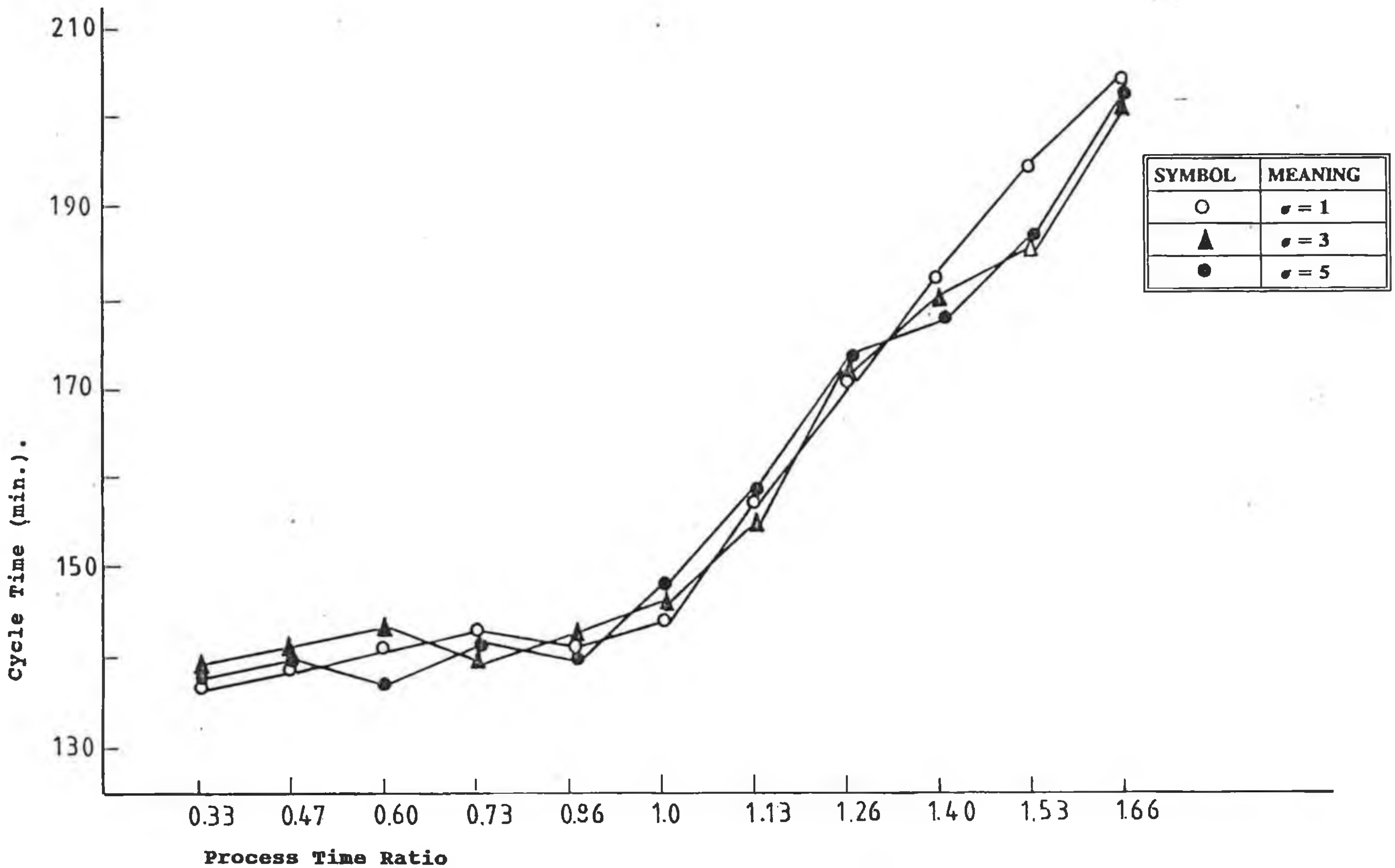
Production Rate

Fig (8.11) shows the effect of variability at final assembly for the the three variance values. When the final assembly processing times are less than that of the other stations, very little change in system output occurs. However as soon as the balanced configuration has been passed the system output drops of sleeply, with quite small changes in processsing time. The actual variance value, only has a slight effect on output.

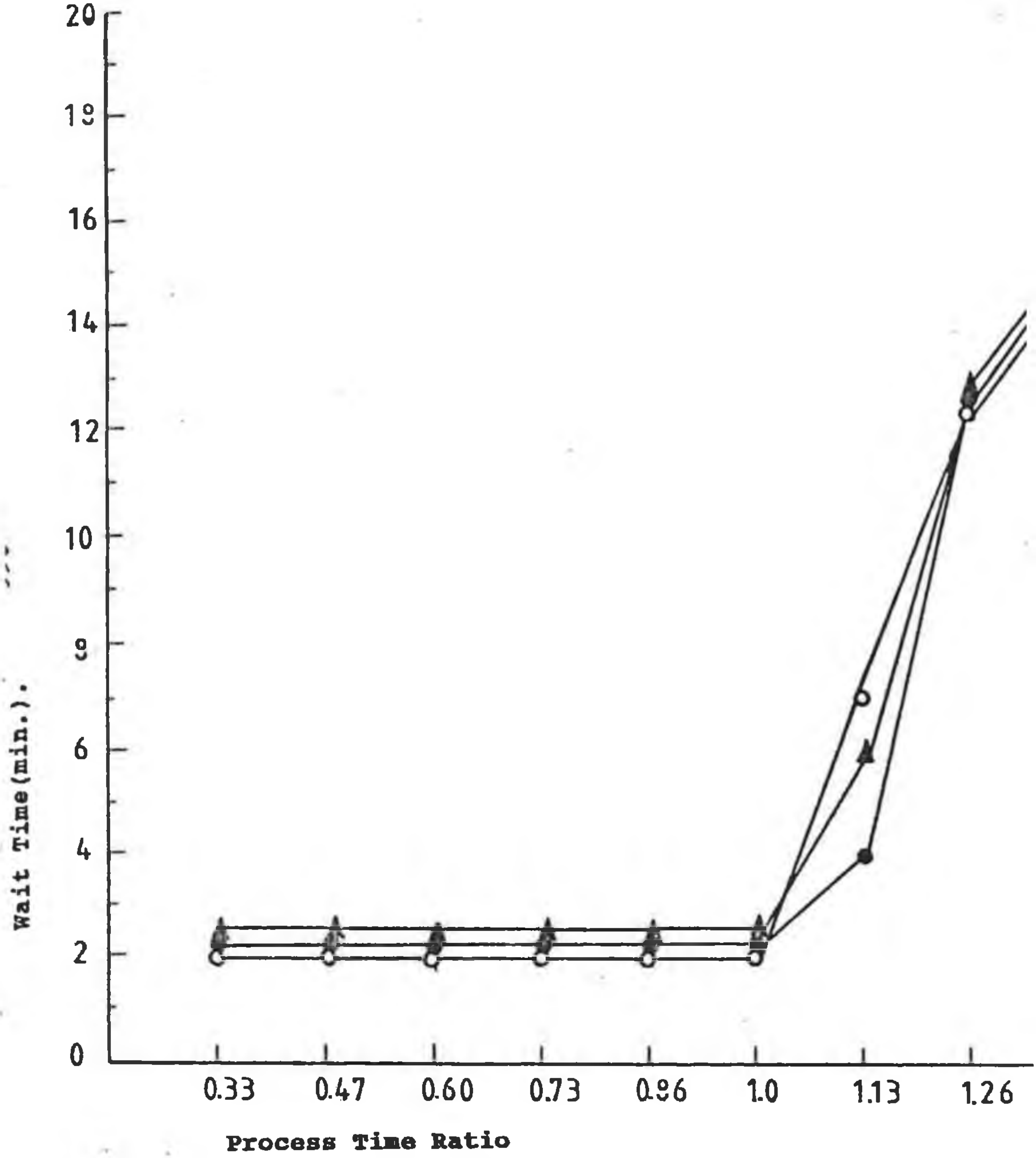
The graph suggests therefore, that final assembly processing time should never rise above that of other work stations in the line.

Cycle Time

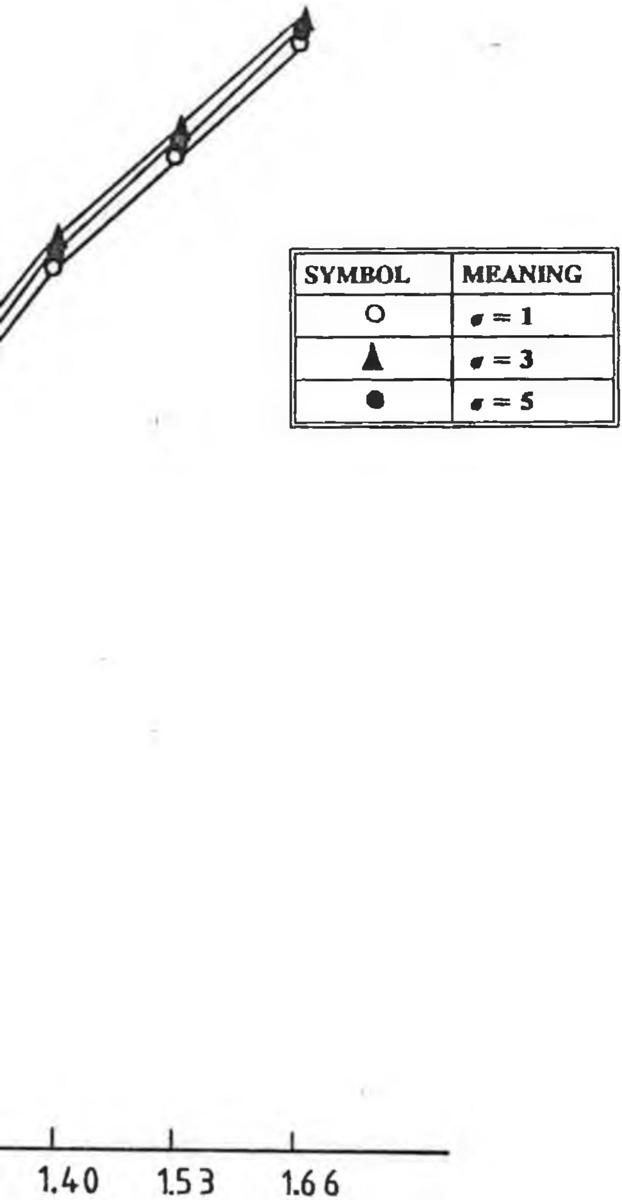
The relationship between cycle time and production rate is emphasised by the final

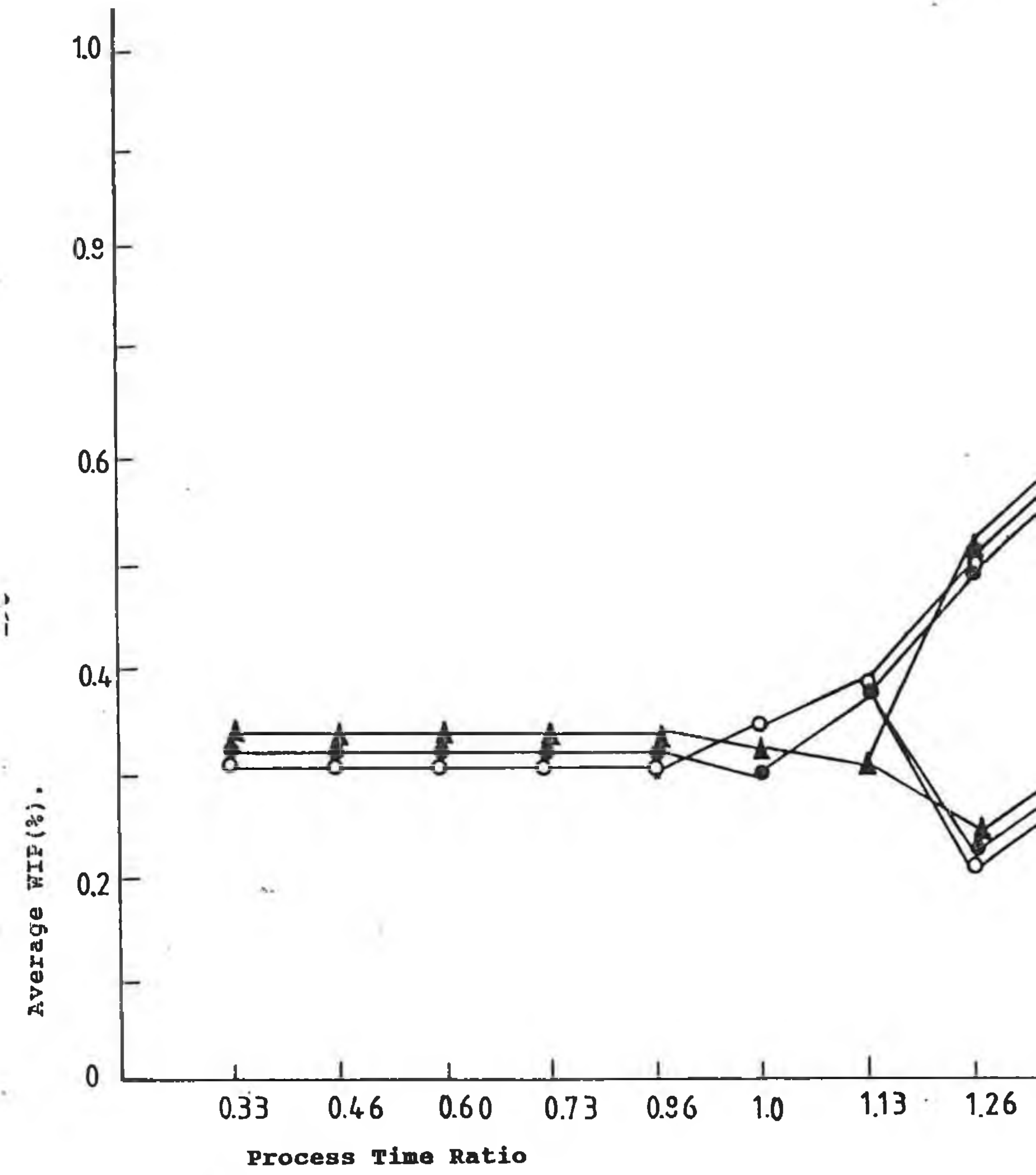


Variation in Cycle Time with Final Assembly Variability. **Fig.(8.12).**



Variation in Wait Time with [illegible]


SYMBOL
MEANING
σ = 1
σ = 3
σ = 5
1.40
1.53
1.66



Variation in Overall WIP with Final Assembly Variability.

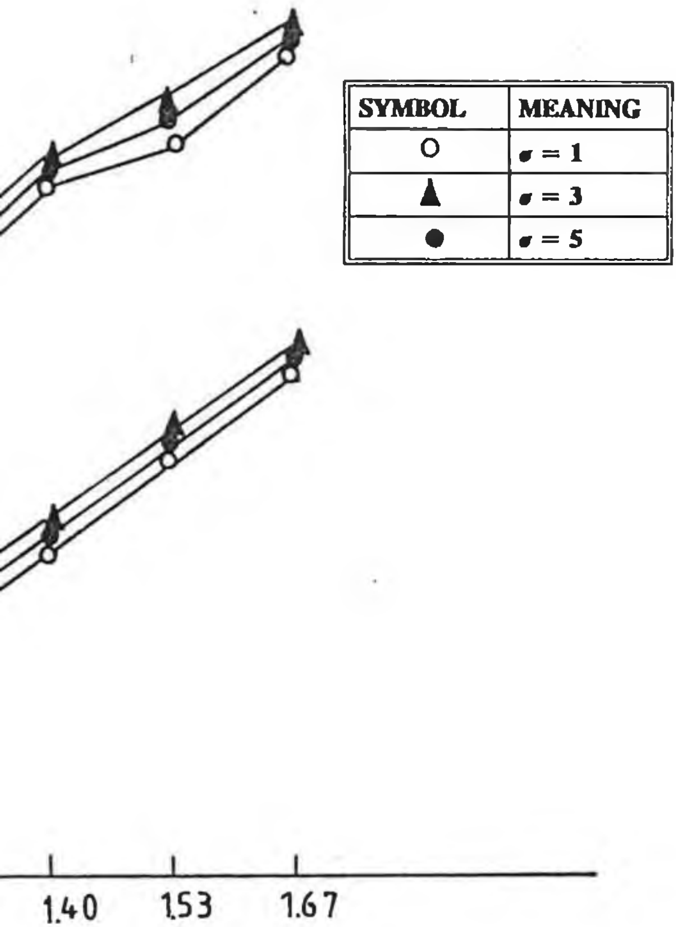


Fig.(8.14).

assembly graphs. At low values of PTR, the production rate is very high, and the cycle time very low as the PTR value increases beyond the balanced state, the cycle times increase, as the production rate drops off. Again the actual variance value has very little effect on the rate of change of cycle times and production rate. (Fig. 8.12). Notice that the wait time at final assembly follows cycle time (Fig. 8.13).

__Total System WIP__

The sudden change in the performance of both graphs however coincides with a sudden increase in the WIP in the system, as the PTR value passes through balance. (See Fig. 7.12). The average WIP in the input buffer begins to increase, and the output buffer, which has previously been used only as a transitionary point, is now being used as an actual storage facility. Once WIP appears in the output buffer, the average WIP held increases at a similar rate to the increase in the input buffer, but at much lower values.

An increase in variance values has very little effect in the performance of either input or output buffers.

8.8 DISCUSSION/CONCLUSIONS

Blocking is said to occur within a manufacturing system, when a succeeding buffer is full. Conversely starving may occur when a preceding buffer is empty. Therefore it may be concluded that the first station in a line can never be starved of parts and the final station in a line can never be blocked. Intermediary stations however may be both blocked and starved causing the greatest effect at the adjacent stations. If a particular work station is blocked, the operation of the line may be split into two distinct segments by the blocked work station. Processing continues at all preceding work stations, until each of them is blocked. (The adjacent station being block first). Processing continues at succeeding stations until each is successively starved.

Section (8.7.1) examines various system configurations. Graphs (8.5), show the effects of these configurations at the WIP levels at various work stations in an assembly line.

The cantilever case graphs (Fig. 8.3a) show that as the processing time for the first station increases, a blocking effect, begins to occur, at work station and the level of WIP increases in this input buffer and reduces in the input buffers of the other two stations (ie. starved). The adjacent work station however experiences the most rapid reduction in WIP level. This increased blocking effect causes a drop off in the production rate (Fig. 8.4), an increase in cycle time (Fig. 8.5), and a drop off in resource utilizations at work stations 2, and 3 as they are starved for parts.

The see saw graphs presented (Figs. 8.5b) can also be explained in terms of blocking and starving. At low values of PTR, the blocking effect of work station 3 tends to dominate the WIP level at the intermediary station. Once the balanced position has been passed through however, the level of WIP at work station 2 is now subject to blocking at work station 1 and follows trends in work station 1. The last work station in the line, however, is now subject to the combined blocking effect of work stations 2 and 1, and the WIP level drops off completely.

The symmetry of each of the see saw graphs (Figs. 8.3b, 8.4b, 8.5b) tend to agree with the conjecture of Hillier and Boling (see Silver et al) that the optimal allocation of processing time is symmetric, and blocking at the beginning of a line, causes a similar variation in performance parameters, as starving at the end of a line.

The bowl graphs demonstrate that the initial stations are relatively unaffected in these configurations. At low values of PTR, work stations 3 is subjected to the blocking effects of work station 2, and consequently is starved of WIP in the input buffer. The level of WIP at work station 2 decreases slowly as the PTR value increases and all the processing times align. As the processing times at work stations 1, and 3 rise above that of work station 2, the blocking is eased slightly and the level of inventory at stations 2 and 3, begin to steady out.

TABLE (8.2): Best Available Results For Each Configuration.

Performance Parameter / System Configuration	P. RATE (Units)	CYCLE TIME (Min)	WIP (%)	RES UTIL (%)
4 Stage Bowl	32	114	37	93
3 Stage Bowl	32	136	50	93
Cantilever	31	127	34	95
Balanced	30	126	56	94
See Saw	28	150	30	89

Table (8.3), presents the best available results for each of the configurations. It would appear that the two bowl type configurations tend to provide the best protection against the effects of both blocking and starving. When the bowl is completed by final assembly (4 Stage Bowl), the performance parameters are stabler over longer periods of time.

Increasing the number of cards within the system, automatically increases the WIP in capacity of the system. The blocking and starving effects tend to intensify as the number of cards are increased, (1-2) causing a reduction in production rate (Fig. 8.8) and an increase in both WIP values, and cycle times (Figs 8.9, 8.10). Further increases in the number of cards (2 -3), however, do not tend to bring about such great changes in system performance parameters.

In all, except the last experiment, the processing time at final assembly was held constant. Comparing (Figs. 8.3a, 8.11), it may be shown that, the effect of variability in both the mean and the variance of processing times has similar effect, on production rate, irrespective of whether it occurs at the first stations in an assembly line or at final assembly. When the variation occurs at final assembly however variations in variance values have less effect on system performance.

This effect is accenuated while in the balanced configuration. (See Figs. 8.3a, 8.11, 8.4a, 8.12). WIP values are much lower, when the variation occurs at final assembly, and are much more stable over longer mean processing time spans.

CONCLUSIONS

1. Different system configurations produce quite different effects in terms of system performance parameters.
2. Bowl type configurations require much smaller changes in mean processing times to produce similar effects in performance parameters than either of the other configurations. Bowl configurations also produce the greatest changes in performance parameters above the balanced case.
3. The balanced configuration does not always produce the most efficient results, in terms of production output, cycle times etc. and may be improved by unbalancing.
4. The Hillier and Boling (See Silver Et Al [ ]), hypotheses on the reversibility of processsing systems, is demonstrated in the set of "See Saw" configuration graphs.
5. At low variance values, the introduction of extra cards causes little change in system performance parameters as the variance increases however the number of cards become increasingly important to the effective control of the system.
6. An increase in variance of processing time, on performance parameters are much less important at final assembly than at the first station in an assembly line.

CHAPTER 9

CONCLUSIONS

9.1 SURVEY OF INVENTORY CONTROL POLICIES

This thesis presents results on inventory control practises within the Irish Electronics Industry. As outlined in the introduction, Chapter 4 presents an overview of inventory control policies in use within the industry as determined by an industrial survey. The main characteristics of these policies are:

1. The industry is predominantly push orientated.
2. In terms of control policies, very little difference exists between large and medium firm size. Small firms however differ markedly from the first two.
3. Industry consists mainly of assembly operations, most of which (93%) have MRP systems.
4. MRP is loosely applied to cover all levels of computerization. However the majority of firms tend to use MRP mainly for order launching. Very few closed loop systems are in operation, and only two 'A' class users are in evidence.
5. In basic MRP terms, only two of the inputs have high levels of computerization - BOM, IR-, the MPS exhibits much lower computerization levels.
6. The majority of firms utilize net change MRP (See Chapter 5). Lot sizing along with other MRP features play an important role in requirements generation.
7. Levels of computerization vary markedly between firms size, with large firms having high levels of computerization, and small firms exhibiting lower levels.
8. Data accuracy is relatively low among MRP elements which are not computerized. Accuracy levels, are low across the spectrum of firm size.

9. JIT awareness is relatively high (70%) across the spectrum of firm size, but implementation tends to be mainly concentrated in the large to medium size category.

10. JIT implementation is concentrated in the JIT delivery area, with cross training of employees and Kanban operation also featuring.

The survey also highlights the problem that although the electronics industry is push based, MRP has failed to permeate all levels of the manufacturing hierarchy, leaving many of the smaller firms with very low levels of computerization, and integration among the varied inventory control functions.

In recent years, the emergence of JIT onto the Inventory Control scene has heralded a new departure in inventory management worldwide. The survey shows however that it has tended to be the larger firms who have benefited from this new thinking, with smaller firms retaining the older inventory methods.

If current trends are to change in the future time and money must be spent on educating small firms as to the potential profitability to be gained from a move towards newer inventory control practises.

9.2 LOT SIZING WITHIN MRP

The generation of requirements within MRP is investigated in Chapter 6. The linear programming form of the MRP model, which was developed, and tested under a variety of operating conditions, was found to produce optimum requirements, irrespective of the form of the product structure. The models' performance was found to be enhanced by the introduction of a dynamic planning horizon outlining the conditions under which the model is run.

The models performance was also compared to requirements generated by some of the more widely used lot sizing techniques. In all cases the linear programming model, outperformed, each of the other techniques.

Two important lessons may be learnt from results presented in this section. Firstly, firms interested in cost reduction may achieve greater benefits by switching to the linear programming model. Secondly, smaller firms, frightened by MRP's emphasis on computerization, and the high levels of investment involved should be made to realize that MRP can be performed relatively simply and cheaply on standard mathematical programming packages which can be either purchased or developed internally. All that is required is an understanding of the more rudamentary aspects of MRP.

9.3 KANBAN SIMULATION

Simulation is an as yet untapped management aid. Chapter 8 investigates the operation of a Kanban system through the use of simulation. The first set of experiments were performed, with a view to investigating the effects of process time imbalance on various system perfomance parameters. These experiments show that the balanced configuration does not always produce the best results in terms of performance parameters and that by varying process times at individual stations, work-in-progress levels, machine utilizations and cycle times can be improved upon. Bowl type configurations were found, not only to provide the best protection against blocking and starving, (See Chapter 8) but also in dealing with effects of work station variability. The experiments conducted, also demonstrated the effect of near processing time variability on performance parameters.

The second set of experiments deals with the impact of an increase in the number of cards within the system. The results show that an increase in the number of cards, reduces cycle times, and increases WIP values and cycle times. There comes a point however, where the effects of blocking and starving become saturated and further increases in the number of cards have little effect on parameters.

The final set of experiments, examines, the effect of process time variability on final assembly. Results suggest that once the process time at final assembly exceeds that at other stations, the production rate drops, and therefore should not be allowed to drop below the balance value. Final assembly processing time also effects the value of WIP in the output buffer, once the processing time passes through balance, the WIP value in the input buffer rises above zero. Varying the processing time at other stations does not have such an exagerated effect. Finally, variability in work station mean would appear to have a less noticeable effect when it occurs at final assembly, that at any other work station on the line.

In the future, simulation may play an important role, in the transfer of production systems from push to pull, by allowing managers to forsee the implications and results of changes, and make any adjustments necessary.

9.4 RECOMMENDATIONS FOR FURTHER WORK

1. The development of a good branch and bound procedure, to allow the integration of non-integer lot size requirements within the linear programming model.
2. The introduction of price break facilities into the MRP model.
3. To conduct a similar set of simulation experiments over a much greater number of iterations and for a much larger period to reduce the error margin.
4. The comparison of Push and Pull type systems, performance over a similar range of process time ratios.
5. The development of a complete JIT model, with a user interface so that inexperienced simulators can pick pertinent data from a menu system.

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APPENDIX 1

MRP and JIT Survey Questionnaire

6. Type of Manufacturing: (please tick)

a. Assembly ___ b. Fabrication ___ c. Both ___

7. Type of Process: (please tick)

a. Job Shop ___ b. Continuous Process ___ c. Assembly line ___

8. Approximate number of possible "end-items" in master schedule (excluding service parts): ______________________________

9. Approximate number of different part, component, and assembly numbers: ______________________________

10. Number of levels in the Bill of Material: ______________________________

11. Number of Employees at your Facility: ______________________________

Part B: Description of MRP System Status

1. What is the current and planned status of the following MRP system elements?
(please tick appropriate box)

	Current		Planned	
	Computer-ised	Manual	Computer-ised	Manual
a. Forecasting End Items				
b. Bill of Material				
c. Inventory Stock System				
d. Master Production Schedule				
e. Parts Explosion				
f. Order Release				
g. Purchasing				
h. Capacity Planning (rough cut)				
i. Operations Scheduling				
j. Shop Floor Control				

STUDY OF MATERIAL REQUIREMENTS PLANNING SYSTEMS

The questions in this survey are designed to be answered by the Materials Manager, Production and Inventory Control Manager, or other person who is most familiar with the MRP system in your company. If you encounter questions which you cannot answer or questions which do not apply to your company, please leave them blank. Answer the remaining questions by entering or circling the most appropriate response. When you have completed the questionnaire, please return it in the prepaid return envelope. Thank you for your help.

Part A: Company Description:

1. Title of Respondent: ____________________

2. Your Company's Industry: ____________________

3. If any please state name of parent plant/company: ____________________

4. Please tick product/description which most suits your product.

   a. Electronic Computers: ___

   b. Electro-Mechanical (Indust.): ___

   c. Electro-Mechanical (Consum.): ___

   d. Electronic components: ___

5. Type of Products: (please tick)

   a. Make-to-Order ___ b. Make-to-Stock ___ c. Both ___

2. Which of the following features does your MRP system have? Please circle the correct answer.

a.	Update Method:	Net Change	Regenerative
b.	Pegging:	Yes	No
c.	Cycle Counting:	Yes	No
d.	Automatic lot sizing by computer:	Yes	No

3. What is the accuracy of the following types of data? (please circle correct answer)

		Poor	Fair	Good	Excellent
a.	Inventory Records	1	2	3	4
b.	BOM Records	1	2	3	4
c.	Market Forecasts	1	2	3	4
d.	Master Production Schedule	1	2	3	4
e.	Production Lead Times	1	2	3	4
f.	Vendor Lead Times	1	1	3	4
g.	Shop Floor Control Data	1	2	3	4
h.	Capacity Plan	1	2	3	4

4. How is the term "MRP" used in your company.

a. ____________ In the broad sense, as a closed-loop manufacturing control system.

b. ____________ In the narrow sense, as parts explosion and order launching.

c. Other (Please describe)____

Part C: MRP Benefits and Costs:

1. To what degree have the following benefits been achieved from your MRP system. (please circle correct answer)

		Degree of Improvement			
		Little/ None	Some	Much	Very Much
a.	Improved customer satisfaction	1	2	3	4
b.	Better production scheduling	1	2	3	4
c.	Improved manufacturing lead times	1	3	3	4
d..	Better control inventory	1	2	3	4

Part D: Implementation Problems:

1. To what extent have you encountered the following types of problems with data accuracy, availability, or format, in implementing your MRP system? (please circle correct answer)

	Degree of Problem			
	Little/ None	Some	Much	Very Much
a. Master production schedule	1	2	3	4
b. Production lead times	1	2	3	4
c. Lack of suitability of software	1	2	3	4
d. Constraint of computer hardware	1	2	3	4
e. Lack of company expertise in MRP	1	2	3	4
f. High cost of the MRP system	1	2	3	4

2. What is the major problem your firm has faced in implementing MRP? ______

____

Part E: Implementation Approach Used:

1. To what extent were the following sources of expertise and information used regarding MRP? (please circle correct answer)

	Little/ None	Some	Much	Very Much
a. Consultants	1	2	3	4
b. Computer manufacturers	1	2	3	4
c. Software vendors	1	2	3	4
d. Books or periodicals	1	2	3	4

2. What was the source of software for your MRP system? (please tick)

   a. ___ Vendor supplied with: (i) __ modification (ii) __ No modification

   b. ___ Developed internally

Part F:

1. Do you think J.I.T. may be applied successfully in your manufacturing environment. (please tick)

   a. Yes   b. No

2. Have you implemented any aspects of J.I.T.

   a. Yes   b. No

3. If yes: What elements: (please tick)

   a. ______ Reduce set-ups

   b. ______ Group technology

   c. ______ T.P.M. program

   d. ______ Cross training employees

   e. ______ Kanban

   f. ______ J.I.T. delivery/purchasing

   g. ______ Uniform work loads

   h. ______ Zero defects/quality circles

4. If No: Do you intend to in the future.

   a. Yes   b. No

5. If Yes: (please tick elements) a. __ b. __ c. __ d. __ e. __

   f. __ g. __ h. __

APPENDIX 2

LINPROG 2 MRP Model Input and Results

```
MIN
40P11+10P12+5P13+1P14+2I11+2I12+2I13+2I14+40P21+10P22+5P23+2I21+2I22+2I2
+2I24+40P31+10P32+5P33+2I31+2I32+2I33+2I34+40P41+10P42+2I41+2I42+40P51+1
+2I51
-I11+P11=1                                "PERIOD ONE"
I11-I12+P12=1                                "PERIOD TWO"
I12-I13+P13=1                                "PERIOD THREE"
I13+P14=1                                "PERIOD FOUR"
-I21+P21-2P11=0
I21-I22+P22-2P12=0
I22+P23-2P13=0
-I31+P31-3P11=0
I31-I32+P32-3P12=0
I32+P33-3P13=0
-I41+P41-2P31=0
I41+P42-2P32=0
-I51+P51-P31=0
I51+P52-P32=0
P41+P41=24
P31+P32+P33=12
P21+P22+P23=8
P11+P12+P13+P14=4
P51+P52=12
[EOB]
                OPTIMAL SOLUTION
   OBJ. FU.     1520.0000
   PRIMAL      SOLUTION          DUAL        SOLUTION
   P11             1.0000    -149400.0000   PERIOD ONE
   P12             1.0000    -149688.0000   PERIOD TWO
   P13             2.0000    -149697.0000   PERIOD THREE
   I13             1.0000    -149695.0000   PERIOD FOUR
   P21             2.0000      -9960.0000
   P22             2.0000      -9990.0000
   P23             4.0000      -9995.0000
   P31             3.0000     -39840.0000
   P32             9.0000     -39906.0000
   I32             6.0000     -39904.0000
   P41            24.0000      -9960.0000
   I41            18.0000      -9958.0000
   P51             3.0000      -9960.0000
   P52             9.0000     -10000.0000
   R15             0.0000      10000.0000
   R16             0.0000      10000.0000
   R17             0.0000      10000.0000
   R18             0.0000      10000.0000
   R19             0.0000      10000.0000
```

```
MIN
4P11+3P12+2P12+1P14+2I11+2I12+2I13+2I14+4P21+3P22+2P23+1P24+2I21+2I22+2I
+2I24+4P31+3P32+2P33+1P34+2I31+2I32+2I33+2I34+4P41+3P42-2I41+2I42
-I11+P11=1                                       "PERIOD ONE"
I11-I12+P12=1                                       "PERIOD TWO"
I12-I13+P13=1                                       "PERIOD THREE"
I13-I14+P14=1                                       "PERIOD FOUR"
-I21+P21-2P11=0
I21-I22+P22-2P12=0
I22-I23+P23-2P13=0
-I31+P31-3P11=0
I31-I32+P32-3P12=0
I32+P33-3P13=0
-I41+P41-P31=0
I41-I42+P42-P32=0
P41+P41=12
P31+P32+P33=12
P21+P22+P23=8
P11+P12+P13+P14=4
I14=0
I23=0
I42=0
```

OPTIMAL SOLUTION

OBJ. FU. 148.0000

PRIMAL	SOLUTION	DUAL	SOLUTION
P11	1.0000	-59991.0000	PERIOD ONE
P12	1.0000	-59991.0000	PERIOD TWO
I32	6.0000	-59990.0000	PERIOD THREE
I13	1.0000	-59988.0000	PERIOD FOUR
P21	2.0000	-9996.0000	
P22	2.0000	-9997.0000	
P23	4.0000	-9998.0000	
P31	3.0000	-10001.0000	
P32	9.0000	-10000.0000	
P33	0.0000	-9998.0000	
P41	12.0000	-5.0000	
I41	9.0000	-3.0000	
I42	0.0000	9.0000	
R14	0.0000	10000.0000	
R15	0.0000	10000.0000	
R16	0.0000	10000.0000	
I14	0.0000	-59986.0000	
I23	0.0000	-9996.0000	
P13	2.0000	-1.0000	

```
MIN
1P11+13P12+2P12+41P14+2I11+2I12+2I13+2I14+1P21+1P22+12P23+1P24+2I21+2I22
+2I23+2I24+4P31+3P32+2P33+1P34+2P31+2P32+2P33+2P34
-I11+P11=1                                  "PERIOD ONE"
I11-I12+P12=1                                  "PERIOD TWO"
I12-I13+P13=1                                  "PERIOD THREE"
I13-I14+P14=1                                  "PERIOD FOUR"
-I21+P21-2P11=0
I21-I22+P22-2P12=0
I22-I23+P23-2P13=0
-I31+P31-3P11=0
I31-I32+P32-3P12=0
I32-I33+P33-3P13=0
P31+P32+P33=12
P21+P22+P23=8
P11+P12+P13+P14=4
I33=0
P34=0
I14=0
I23=0
P24=0
[EOB]
```

OPTIMAL SOLUTION

OBJ. FU. 58.0000

PRIMAL	SOLUTION	DUAL	SOLUTION
P11	2.0000	-19995.0000	PERIOD ONE
I11	1.0000	-19993.0000	PERIOD TWO
P12	2.0000	-19993.0000	PERIOD THREE
I12	1.0000	-19996.0000	PERIOD FOUR
P21	4.0000	9996.0000	
P22	4.0000	9996.0000	
I22	4.0000	9998.0000	
P31	6.0000	-9996.0000	
P32	0.0000	-9997.0000	
P33	6.0000	-9995.0000	
R1.	0.0000	10000.0000	
I23	0.0000	-9995.0000	
R13	0.0000	10000.0000	
I33	0.0000	-9998.0000	
P34	0.0000	1.0000	
I14	0.0000	-19994.0000	
R17	0.0000	10000.0000	
P24	0.0000	1.0000	

```
               OPTIMAL SOLUTION
OBJ. FU.        47.0000
PRIMAL        SOLUTION          DUAL        SOLUTION
P11             1.0000     -19995.0000    PERIOD ONE
P12             1.0000     -19994.0000    PERIOD TWO
P13             2.0000     -19995.0000    PERIOD THREE
I13             1.0000     -19993.0000    PERIOD FOUR
P21             4.0000      -9999.0000
I21             3.0000      -9997.0000
I22             2.0000      -9995.0000
P31             1.0000     -19992.0000
P32             1.0000     -19994.0000
P33             2.0000     -19996.0000
I33             1.0000     -19994.0000
P41             1.0000      -9996.0000
P42             1.0000      -9997.0000
P43             2.0000      -9998.0000
R15             0.0000      10000.0000
R16             0.0000      10000.0000
R17             0.0000      10000.0000
R18             0.0000      10000.0000
```

```
MIN
4P11+3P12+2P12+1P14+2I11+2I12+2I13+1P21+13P22+12P23+11P24-2I21-2I22+2I[illegible]
+3P32+2P33+1P34+2I31+2I32+2I33+2I34+4P41+3P42+2P43+1P44+2I41+2I42+2I43
-I11+P11=1                                      "PERIOD ONE"
I11-I12+P12=1                                      "PERIOD TWO"
I12-I13+P13=1                                      "PERIOD THREE"
I13+P14=1                                      "PERIOI FOUR"
-I21+P21-P11=0
I21-I22+P22-P12=0
I22+P23-P13=0
-I31+P31=1
I31-I32+P32=1
I32-I33+P33=1
I33+P34=1
-I41+P41-P31=0
I41-I42+P42-P32=0
I42+P43-P33=0
P11+P12+P13+P14=4
P21+P22+P23=4
P41+P42+P43=4
P31+P32+P33+P34=4
[EOB]
```

OPTIMAL SOLUTION

OBJ. FU.	34.0000		
PRIMAL	SOLUTION	DUAL	SOLUTION
P21	4.0000	-29991.0000	PERIOD ONE
P12	1.0000	-29991.0000	PERIOD TWO
P13	2.0000	-29993.0000	PERIOD THREE
I13	1.0000	-29991.0000	PERIOD FOUR
I20	0.0000	-9999.0000	
I21	3.0000	-9997.0000	
I22	2.0000	-9995.0000	
I30	0.0000	-9996.0000	
P32	1.0000	-9997.0000	
P33	2.0000	-9998.0000	
P11	1.0000	9996.0000	
I33	0.0000	-9996.0000	
P31	1.0000	9999.0000	
I23	0.0000	-9993.0000	
R15	0.0000	10000.0000	
I14	0.0000	-29989.0000	
R17	0.0000	10000.0000	
R18	0.0000	10000.0000	
R19	0.0000	10000.0000	

```
4P11+3P12+2P12+1P14+2I11+2I12+2I13+2I14+1P21+13P22+12P23+11P24+2I21+2I22
2I24+4P31+3P32+2P33+1P34+2I31+2I32+2I33+2I34
I10-I11+P11=1                                   "PERIOD ONE"
I11-I12+P12=1                                   "PERIOD TWO"
I12-I13+P13=1                                   "PERIOD THREE"
I13-I14+P14=1                                   "PERIOD FOUR"
I20-I21+P21-P11=0
I21-I22+P22-P12=0
I22-I23+P23-P13=0
I30-I31+P31-P11=0
I31-I32+P32-P12=0
I32-I33+P33-P13=0
I30=0
I33=0
I20=0
I23=0
I10=0
I14=0
P11+P12+P13+P14=4
P21+P22+P23=4
P31+P32+P33=4
```

OPTIMAL SOLUTION

OBJ. FU. 39.0000

PRIMAL	SOLUTION	DUAL	SOLUTION
P31	1.0000	-29988.0000	PERIOD ONE
P12	1.0000	-29991.0000	PERIOD TWO
P13	2.0000	-29992.0000	PERIOD THREE
I13	1.0000	-29990.0000	PERIOD FOUR
R12	0.0000	-19992.0000	
P22	3.0000	-19994.0000	
I22	2.0000	-19992.0000	
I30	0.0000	-9996.0000	
P32	3.0000	-9997.0000	
P21	1.0000	9996.0000	
I32	0.0000	-9995.0000	
P11	1.0000	10000.0000	
I23	0.0000	-19990.0000	
R14	0.0000	10000.0000	
I14	0.0000	-29988.0000	
R16	0.0000	10000.0000	
R17	0.0000	10000.0000	
R18	0.0000	10000.0000	

```
MIN
4P11+3P12+2P12+1P14+2I11+2I12+2I13+2I14+4P21+3P22+2P23+1P24+2I21+2I22+2I
+4P31+3P32+2P33+1P34+2I31+2I32+2I33+2I34
I10-I11+P11=1                                "PERIOD ONE"
I11-I12+P12=1                                "PERIOD TWO"
I12-I13+P13=1                                "PERIOD THREE"
I13-I14+P14=1                                "PERIOD FOUR"
I20-I21+P21-P11=0
I21-I22+P22-P12=0
I22-I23+P23-P13=0
I30-I31+P31-P21=0
I31-I32+P32-P22=0
I30=0
I32=0
I20=0
I23=0
I10=0
I14=0
```

APPENDIX 3A

SCICONIC Model Input

```
SUFFICES
 A MAXA 1
 I MAXI 5
C
C MAX NUMBER OF FACILITIES
C
 T MAXT 25
C
C MAX NO OT TIME PERIODS
C
EXTERNAL VALUES
 PCOSTS(I,T)
C
C PRODUCTION COSTS DEFINED FOR EACH FACILITY IN EVERY TIME PERIOD
C
 HCOSTS(I,T)
C
C HOLDING COSTS DEFINED FOR EACH FACILITY IN EACH TIME PERIOD
C
 DEM(T)
C
C DEMAND AT FINAL FACILITY IN EVERY TIME PERIOD
C
VARIABLES
 IN(I,T) '**IT'
C
C INVENTORY CARRIED FROM PERIOD TO NEXT PERIOD
C
 PR(I,T) '**IT'
C
C INVENTORY PRODUCED IN A GIVEN PERIOD AT A GIVEN FACILITY
C
PROBLEM
MINIMISE
*COST '****'
  SUM(I,T)    P01*PR(I,T)
 +SUM(I,T)    H01*IN(I,T)
SUBJECT TO
*MATBB  '*****IT'
 IN(I,T1)-IN(I,T)+PR(I,T).EQ.D01
FOR ALL T
FOR I=1
FOR T1=T-1
C
C MATERIAL BALANCE CONSTRAINT AT FIRST FACILITY
C
*MATB  '****IT'
 IN(I,T1)-IN(I,T)+PR(I,T)-PR(I1,T).EQ.C01
FOR I=2
FOR T1=T-1
FOR I1=I-1
```

```
FOR ALL T
C
C MATERIAL BALANCE AT SECOND FACILITY
*MAT   '***IT'
 IN(I,T1)-IN(I,T)+PR(I,T)-PR(I1,T).EQ.C01
FOR I=3
FOR T1=T-1
FOR I1=I-2
FOR ALL T
C
C MATERIAL BALANCE AT THIRD FACILITY
C
*CAP  '***I'
  SUM(T)  PR(I,T).EQ.Q01
FOR I=1
C
C ACCUMULATED PRODUCTION AT THE FIRST FACILITY
C
C
ELEMENTS
      P01=PCOSTS(I,T)
      H01=HCOSTS(I,T)
      D01=DEM(T)
      C01=0.0
      Q01=24.0
ENDATA
```

APPENDIX 3B

Matrix Generation Data File

```
EXTERNAL VALUES
KANAME  1       DUMMY
*       I       MNEMONIC
KINAME  1       FACONE
KINAME  2       FACTWO
KINAME  3       FACTHR
*       T       MNEMONIC
KTNAME  1       PERONE
KTNAME  2       PERTWO
KTNAME  3       PERTHRE
KTNAME  4       PERFOUR
KTNAME  5       PERFIVE
KTNAME  6       PERSIX
*PRODUCTION COSTS
*                    PER1      PER2      PER3      PER4      PER5      PER6
PCOSTS FACONE        10        5         10        5         10        5
PCOSTS FACTWO        10        5         1         1         5         10
PCOSTS FACTHR        1         5         10        10        5         1
*HOLDING COSTS
*                    PER1      PER2      PER3      PER4      PER5      PER6
HCOSTS FACONE        1         1         1         1         1         1
HCOSTS FACTWO        1         1         1         1         1         1
HCOSTS FACTHR        1         1         1         1         1         1
*DEMAND
*             PER1      PER2      PER3      PER4      PER5      PER6
DEM           6         0         7         2         8         1
ENDATA
```

APPENDIX 3C

Matrix File

```
NAME          eeeeeeee                 MINIMISE
ROWS
 N  COST....
 E  CAP2....
 E  CAPP1...
 E  MATB21..
 E  MATB22..
 E  MATB23..
 E  MATB24..
 E  MATBB11.
 E  MATBB12.
 E  MATBB13.
 E  MATBB14.
COLUMNS
    IN11....  COST....      2.         MATBB12.      1.
    IN11....  MATBB11.     -1.
    IN21....  COST....      2.         MATB22..      1.
    IN21....  MATB21..     -1.
    IN12....  COST....      2.         MATBB13.      1.
    IN12....  MATBB12.     -1.
    IN22....  COST....      2.         MATB23..      1.
    IN22....  MATB22..     -1.
    IN13....  COST....      2.         MATBB14.      1.
       3....  MATBB13.     -1.
    IN23....  COST....      2.         MATB24..      1.
    IN23....  MATB23..     -1.
    IN14....  COST....      2.         MATBB14.     -1.
    IN24....  COST....      2.         MATB24..     -1.
    PR11....  COST....     14.         CAPP1...      1.
    PR11....  MATB21..     -1.         MATBB11.      1.
    PR21....  COST....      4.         CAP2....      1.
    PR21....  MATB21..      1.
    PR12....  COST....     13.         CAPP1...      1.
    PR12....  MATB22..     -1.         MATBB12.      1.
    PR22....  COST....      3.         CAP2....      1.
    PR22....  MATB22..      1.
    PR13....  COST....      2.         CAPP1...      1.
    PR13....  MATB23..     -1.         MATBB13.      1.
    PR23....  COST....     22.         CAP2....      1.
    PR23....  MATB23..      1.
    PR14....  COST....      1.         CAPP1...      1.
    PR14....  MATB24..     -1.         MATBB14.      1.
      24....  COST....     11.         CAP2....      1.
    PR24....  MATB24..      1.
RHS
    RHSSET01  CAP2....      4.         CAPP1...      4.
    RHSSET01  MATBB11.      1.         MATBB12.      1.
    RHSSET01  MATBB13.      1.         MATBB14.      1.
ENDATA
```

APPENDIX 3D

SCICONIC Results

PROBLEM @@@@@@@@ - SOLUTION NUMBER 1 - OPTIMAL

CREATED ON 26-FEB-1991 19:42:50.24 , AFTER 10 ITERATIONS

PRINTED ON 26-FEB-1991 19:43:16.94

...NAME...	..ACTIVITY..	DEFINED AS
FUNCTIONAL	49.000000	COST....
RESTRAINTS		RHSSET01

	NUMBER	..ROW...	AT	....ACTIVITY....	.SLACK ACTIVITY.	..LOWER BOUND...	..UPPER BOUND...	.DUAL ACTIVITY.
N	1	COST....	BS	49.000000	-49.000000	NONE	NONE	1.00000
E	2	CAP2....	EQ	4.000000	.	4.000000	4.000000	.
E	3	CAPP1...	EQ	4.000000	.	4.000000	4.000000	.
E	4	MATB21..	EQ	.	.	.	.	-4.00000
E	5	MATB22..	EQ	.	.	.	.	-3.00000
E	6	MATB23..	EQ	.	.	.	.	-5.00000
E	7	MATB24..	EQ	.	.	.	.	-7.00000
E	8	MATBB11.	EQ	1.000000	.	1.000000	1.000000	-18.00000
E	9	MATBB12.	EQ	1.000000	.	1.000000	1.000000	-16.00000
E	10	MATBB13.	EQ	1.000000	.	1.000000	1.000000	-7.00000
E	11	MATBB14.	EQ	1.000000	.	1.000000	1.000000	-8.00000

NUMBER	.COLUMN.	AT	....ACTIVITY....	...INPUT COST...	..LOWER BOUND...	..UPPER BOUND...	..REDUCED COST..
12	IN11....	LL	.	2.000000	.	NONE	4.000000
13	IN21....	LL	.	2.000000	.	NONE	3.000000
14	IN12....	LL	.	2.000000	.	NONE	11.000000
15	IN22....	BS	2.000000	2.000000	.	NONE	.
16	IN13....	LL	.	2.000000	.	NONE	1.000000
17	IN23....	BS	1.000000	2.000000	.	NONE	.
18	IN14....	LL	.	2.000000	.	NONE	10.000000
19	IN24....	LL	.	2.000000	.	NONE	9.000000
20	PR11....	BS	1.000000	14.000000	.	NONE	.
21	PR21....	BS	1.000000	4.000000	.	NONE	.
22	PR12....	BS	1.000000	13.000000	.	NONE	.
23	PR22....	BS	3.000000	3.000000	.	NONE	.
24	PR13....	BS	1.000000	2.000000	.	NONE	.
25	PR23....	LL	.	22.000000	.	NONE	17.000000
26	PR14....	BS	1.000000	1.000000	.	NONE	.
27	PR24....	LL	.	11.000000	.	NONE	4.000000

APPENDIX 4A

SIMAN Model File

```
BEGIN,YES;
CREATE,1:EX(11,1);
        COUNT:1,1;
        DUPLICATE:1,UPD1:1,UPD2:1,UPD3:NEXT(DISP);
UPD1    COUNT:2,1;
        ASSIGN:IS=0:A(4)=1:A(1)=1:MARK(7);
        ASSIGN:NS=A(4):NEXT(CHECKO);
UPD2    COUNT:3,1;
        ASSIGN:IS=0:A(4)=2:A(1)=4:MARK(7);
        ASSIGN:NS=A(4):NEXT(CHECKO);
UPD3    COUNT:4,1;
        ASSIGN:IS=0:A(4)=3:A(1)=7:MARK(7);
        ASSIGN:NS=A(4):NEXT(CHECKO);
;
CHECKO  BRANCH,1:IF,NQ(A(1)).LT.X(A(1)),GO:
                 ELSE,WAITO;
WAITO   QUEUE,52;
        WAIT:A(1),1;
        BRANCH,1:ALWAYS,CHECKO;
GO      ROUTE:0,SEQ;
;
        STATION,1-9;
;
        QUEUE,M;
        SEIZE:STCKPT1(M);
        QUEUE,M+10;
        SEIZE:WKCTR(M);
        SIGNAL:M;
        DELAY:A(2);
        RELEASE:WKCTR(M);
CHECKP  BRANCH,1:IF,NQ(M+30).LT.X(M+30),GOO:
        ELSE,WAITP;
WAITP   QUEUE,M+20;
        WAIT:M+10,1;
        BRANCH,1:ALWAYS,CHECKP;
GOO     RELEASE:STCKPT1(M);
        QUEUE,M+30;
        SEIZE:STCKPT2(M);
CHECKQ  BRANCH,1:IF,M.EQ.3.AND.A(4).EQ.1,FA1:
                 IF,M.EQ.6.AND.A(4).EQ.2,FA2:
                 IF,M.EQ.9.AND.A(4).EQ.3,FA3:
                 IF,NQ(A(1)).LT.X(A(1)),GOO:
                 ELSE,WAITTP;
;
WAITTP  QUEUE,M+40;
        WAIT:A(1),1;
        BRANCH,1:ALWAYS,CHECKQ;
FA1     COUNT:5,1;
        TALLY:A(4),INT(7):MARK(3);
        ASSIGN:A(4)=4:IS=0:NS=A(4);
FA11    QUEUE,60:DETACH;
FA2     COUNT:6,1;
        TALLY:A(4),INT(7):MARK(3);
        ASSIGN:A(4)=4:IS=0:NS=A(4);
FA22    QUEUE,61:DETACH;
FA3     COUNT:7,1;
        TALLY:A(4),INT(7):MARK(3);
        ASSIGN:A(4)=4:IS=0:NS=A(4);
FA33    QUEUE,62:DETACH;
        MATCH:
              FA11,CHECKQ:
              FA22,CHECKQ:
              FA33,CHECKQ:
```

```
GOO      RELEASE: STCKPT2(M);
         SIGNAL:M+10;
;
         BRANCH,1:IF,A(4).EQ.4,GRP:
;
         ELSE,CONTD;
GRP      COUNT:8,1;
         QUEUE,63;
         COMBINE:3,FIRST;
;
CONTD    ROUTE:0,SEQ;
;
;
         STATION,10;
         COUNT:9,1;
         TALLY:A(4),INT(3);
         QUEUE,M;
         SEIZE:STCKPT1(M);
         QUEUE,M+10;
         SEIZE:WKCTR(M);
         SIGNAL:M;
         DELAY:A(2);
         RELEASE:WKCTR(M);
         RELEASE:STCKPT1(M);
         COUNT:10,1;
         TALLY:5,INT(7):DISPOSE;
;
DISP     COUNT:11,1:DISPOSE;
END;
```

APPENDIX 4B

SIMAN Experimental File

```
BEGIN,,YES;
PROJECT,KANBAN,TG,20/6/90;
;
DISCRETE,250,7,65,10;
ATTRIBUTES:7;
;
RESOURCES:1-10,WKCTR,1,:
          11-20,STCKPT1,1:
          21-30,STCKPT2,1;
;
INITIALIZE,X(1)=1,X(2)=1,X(3)=1,X(4)=1,X(5)=1,X(6)=1,X(7)=1,X(8)=1,
           X(9)=1,X(10)=1,
           X(31)=1,X(32)=1,X(33)=1,X(34)=1,X(35)=1,X(36)=1,X(37)=1,
           X(38)=1,X(39)=1,X(40)=1;
;
SEQUENCES:1, 1,2,RN(1,1)& 2,3,RN(2,1)& 3,10,RN(3,1):
          2, 4,5,RN(4,1)& 5,6,RN(5,1)& 6,10,RN(6,1):
          3, 7,8,RN(7,1)& 8,9,RN(8,1)& 9,10,RN(9,1):
          4, 10,,RN(10,1);
;
PARAMETERS:1, 15,.1:
           2, 15,.1:
           3, 15,.1:
           4, 15,.1:
           5, 15,.1:
           6, 15,.1:
           7, 15,.1:
           8, 15,.1:
           9, 15,.1:
           10,17,1:
           11,8;
;
DSTAT: 1,NQ(1),INBUFQ1:
       2,NQ(2),INBUFQ2:
       3,NQ(3),INBUFQ3:
       4,NQ(4),INBUFQ4:
       5,NQ(5),INBUFQ5:
       6,NQ(6),INBUFQ6:
       7,NQ(7),INBUFQ7:
       8,NQ(8),INBUFQ8,"KAN.8":
       9,NQ(9),INBUFQ9,"KAN.9":
       10,NQ(10),INBUFQ10,"KAN.10":
       31,NQ(31),OUTBUFQ1,"KAN.31":
       32,NQ(32),OUTBUFQ2,"KAN.32":
       33,NQ(33),OUTBUFQ3,"KAN.33":
       34,NQ(34),OUTBUFQ4:
       35,NQ(35),OUTBUFQ5:
       36,NQ(36),OUTBUFQ6:
       37,NQ(37),OUTBUFQ7:
       38,NQ(38),OUTBUFQ8:
       39,NQ(39),OUTBUFQ9:
       40,NQ(40),OUTBUFQ10,"KAN.40":
       41,NR(1),UTIL1:
       42,NR(2),UTIL2:
       43,NR(3),UTIL3:
       44,NR(4),UTIL4:
       45,NR(5),UTIL5:
       46,NR(6),UTIL6:
```

```
        47,NR(7),UTIL7:
        48,NR(8),UTLIL8:
        49,NR(9),UTIL9:
        50,NR(10),UTIL10;
;
COUNTERS:1,SYS CREATED:
         2,NO TYP 1:
         3,NO TYP 2:
         4,NO TYP 3:
         5,NO TYP 1 ST.3:
         6,NO TYP 2 ST.6:
         7,NO TYP 3 ST.9:
         8,NO ENT COMB Q:
         9,NO ST 10:
         10,NO DISP ST10:
         11,NO DUP DISP;

;
;REPLICATE,5,0,530,YES,YES,50;
REPLICATE,1,0,480;
;
;
;
TALLIES:1,LEAD.TIME.PT.1:
        2,LEAD.TIME.PT.2:
        3,LEAD.TIME.PT.3:
        4,WAIT TIME FA:
        5,OVERALL FLOWTIME;
;
END;
```

APPENDIX 5

Nomenclature

SUFFICES

1.	*k*:	products\end-items	1...M
2.	*i*:	facilities	1...N
3.	*t*:	time periods	1...T
4.	*d*:	no. of machine resources at a facility	
5.	*(i)*:	immediate successor (parent) of facility *i*	
6.	*Li*:	lead-time stage *i*	

SETS

1.	*P(i)*	set of immediate predecessor stages
2.	*S(i)*	set of all successor stages

VARIABLES

1.	P_{it} (P_{kit})	:	production of product K, facility i, period t.
2.	I_{it} (I_{kit})	:	inventory held product k, facility i, period t.
3.	I_{it}^{+}	:	inventory in storage facility i, period t.
4.	I_{it}^{-}	:	inventory in shortage, at facility i, period t.
5.	Q_i	:	lot size to be determined at facility i.
6.	K_i	:	fixed cost of ordering production at facility i.
7.	P_i	:	production or assembly rate at facility i.
8.	ρ	:	rate at which demand is being met *(D/Pi)*
9.	w_{kt}	:	no. of times product k must be produced in first t periods to ensure positive inventory level at the end of t periods.
10.	X_{kt}	:	no. of facilities scheduled to produce product k during period t.
11.	Y_{it}	:	integer variable value 0,1.
12.	W_{it}	:	summed requirements facility i, less initial inventory due to independent demand less firm scheduled receipts plus and dependent demand from any parent items or for item i in period t.
13.	U_{it}	:	net requirements facility i period t.
14.	S_{it}	:	absolute capacity constraint on further purchasing\production.
15.	U_{dt}	:	undertime requirements at resource d, period t
16.	O_{dt}	:	overtime requirements at resource d, period t.

CONSTANTS

1.	C_{it} (C_{kit}):		production costs product k, facility i, period, t.
2.	H_{kit} (H_{kit}):		holding costs product k, facility i, period t.
3.	D_{it} (D_{kit}):		demand costs product k, facility i, period t.
4.	H_{it+}	:	inventory storage costs at end of period t.
5.	H_{it-}	:	inventory shortage costs at end of period t.
6.	K_i	:	fixed cost of ordering (production) at stage i.
7.	h^1_i	:	holding cost per unit time charged against echelon stock at stage i.
8.	T	:	planning horizon length
9.	Ψ_k	:	production charge per product k, made up of fixed production rate per product (P_k) and a unit inventory charge (ϕ_k) $\Psi = \frac{1}{2}\,\phi_k\,P_k$
10.	P_{it}	:	production capacity facility i, period t.
11.	I_{it}	:	inventory storage capacity facility i, period t.
12.	M_{ki}	:	yield factor at facility i, product k.
13.	S_{it}	:	set-up cost facility i, period t.
14.	E_{id}	:	unit requirement of type d, resource constraint in production at facility i.
15.	M	:	very large no.
16.	I_{io}	:	inventory at facility i, period o.

17. b_{id} : per unit production time, facility i, resource d.

18. S_{id} : set-up time, facility i, resource d.

19. O_{dt} : overtime required, resource d, facility t.

20. U_{dt} : undertime required, resource d, facility t.

21. Co_{dt} : overtime costs required, resource d, facility t.

22. Cu_{dt} : undertime costs required, resource d, facility$t$.

23. Cap_{dt} : total capacity available, resource d, facility t.

APPENDIX 6

Tables of Results: (6.18a, 6.18b, 6.19a, 6.19b)

TABLE (6.18a): Results of Tests

(No Dynamic Planning Horizon)
(Change in Cost Structures)

Planning Horizon Length	TEST A	TEST B	TEST C	TEST D	TEST E	TEST F	AVG
6	0.60	0.61	0.60	0.61	0.59	0.59	0.60
7	0.66	0.65	0.70	0.67	0.67	0.67	0.66
8	0.72	0.74	0.73	0.72	0.74	0.73	0.73
9	0.78	0.79	0.8	0.78	0.75	0.78	0.78
10	0.84	0.86	0.85	0.85	0.85	0.85	0.85
11	0.91	0.92	0.92	0.91	0.89	0.91	0.91
12	1.03	1.06	1.06	1.05	1.03	1.07	1.05

TABLE (6.19a): Results of Tests

(With Dynamic Planning Horizon)
(Change in Cost Structures)

Planning Horizon Length	TEST A	TEST B	TEST C	TEST D	TEST E	TEST F	AVG
6	0.36	0.36	0.40	0.34	0.34	0.36	0.36
7							
8	0.48	0.49	0.47	0.48	0.46	0.50	0.48
9							
10	0.62	0.63	0.61	0.62	0.63	0.61	0.62
11							
12	0.85	0.79	0.79	0.81	0.81	0.81	0.81

TABLE (6.18b): Results of Tests

(No Dynamic Planning Horizon)
(Change in Cost Structures)

Planning Horizon Length	TEST A	TEST B	TEST C	TEST D	TEST E	TEST F	AVG
6	0.44	0.46	0.42	0.43	0.42	0.44	0.44
7	0.46	0.48	0.44	0.43	0.47	0.46	0.46
8	0.48	0.44	0.50	0.45	0.50	0.47	0.47
9	0.50	0.48	0.53	0.49	0.51	0.49	0.50
10	0.52	0.49	0.53	0.54	0.5	0.51	0.52
11	0.54	0.52	0.49	0.55	0.57	0.55	0.54
12	0.56	0.52	0.58	0.59	0.52	0.51	0.55

TABLE (6.19b): Results of Tests

(With Dynamic Planning Horizon)
(Change in Cost Structures)

Planning Horizon Length	TEST A	TEST B	TEST C	TEST D	TEST E	TEST F	AVG
6	0.38	0.40	0.36	0.41	0.36	0.35	0.38
7							
8	0.42	0.44	0.39	0.43	0.42	0.41	0.42
9							
10	0.49	0.50	0.50	0.48	0.47	0.52	0.49
11							
12	0.50	0.51	0.52	0.48	0.49	0.50	0.50